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R.D. WORSFOLD

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R.D. Worsfold

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F.G. Bercha and Associates Limited
Suite 301, 1220 Kensington Road, N.W.
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17. Abstract
Airborne remote sensing techniques for the detection of small objects on the sea surface in a search and rescue situation have been reviewed. Typical targets (20 m length) have been identified together with the 50% and 25% exceedence environmental conditions for typical regions off the east coast of Canada. Remote sensing technologies included in the assessment are infrared, low light level TV and radar systems. In each case, the basic operating principles are summarized together with comments on potential operational limitations, and available information on the performance of the sensors in detection of small objects, both with and without target enhancement aids. Search sweep widths have been computed for average and severe environmental conditions and used as a basis for assessing the potential usefulness of the remote sensing techniques. Information on detection ranges for the various sensors were used to rank their potential effectiveness as a function of increasing sea state. It was concluded that the most promising sensors are television, forward looking infra-red, side-looking radar and forward looking airborne radar. An experimental program is recommended for determination of sweep widths for searches under typical Canadian environmental conditions, using United States Coast Guard experiment methodology as far as possible.

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17. Résumé

Ce rapport rend compte de la recherche sur les systèmes aéroportés de détection de petits objets flottant à la surface de la mer. Il définit les cibles (moins de 20 m de long) à détecter dans les conditions climatiques types correspondant à des situations décrites comme moyennes (50 p.100 de probabilité de dépassement) et difficiles (25 p.100) régnant au large de la côte Est. Les techniques recensées ont été le capteur à infrarouge, la télévision à faible niveau de luminosité et les radars. Le principe fondamental de chaque système est appliqué en donnant en même temps les facteurs susceptibles d'en dégrader les performances. Il renseigne sur l'aptitude des divers capteurs à détecter les objets visés, avec et sans aide extérieure. La largeur du couloir balayé par chacun des systèmes considérés a été calculée pour les deux situations décrites, afin de servir de critère de comparaison. L'information sur les portées utiles a servi à classer chaque système d'après son efficacité face à des états de mer de force croissante. Le rapport montre que la télévision, l'infrarouge et les radars sont les techniques les plus prometteuses. Le rapport recommande un programme de recherche expérimentale visant à déterminer les largeurs de couloirs balayés en détection tant visuelle que radar dans des conditions climatiques canadiennes typiques. Il préconise en outre que ce programme se fonde autant que possible sur la méthodologie mise au point par la Garde côtière américaine.

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EXECUTIVE SUMMARY

The objective of this project has been to assess currently available remote sensing techniques for the detection of small objects on the surface of the ocean. Two parallel studies were commissioned by the Transportation Development Centre (TDC): one by NORDCO Limited of St. John's to evaluate shipborne sensor systems, and a second, which is the subject of this report, by F.G. Bercha and Associates of St. John's to evaluate the effectiveness of airborne remote sensing systems.

Small targets were defined as less than 20 metres (m) in overall length, and included vessels, buoys, oceanographic equipment, persons in the water (PIW's), and debris. Factors such as the shape, size, colour, construction material and detection aids that the target might carry were documented. For the sensor performance analysis four representative targets were selected: 15 m and 7 m vessels, a liferaft and a PIW. Average (50 percent exceedence) and severe (25 percent exceedence) environmental operating conditions have been defined for representative marine forecast areas on the Grand Banks. Average sea conditions generally correspond to sea states 2-3 in the summer and 4-5 in the winter. Severe conditions correspond to sea states 4 in the summer and 5-6 in the winter, noting that the presence of ice is an additional factor in the northern areas during the winter and spring months.

Sensors included in the assessment were forward looking infrared (FLIR), low light level TV (LLLTV) systems and radar systems.

In each case, the basic operating principles of the systems are described, and there is a discussion of factors, that are likely to degrade the performance of the various sensors. Information on sensor performance in detection of the representative targets identified earlier has been obtained from published reports, manufacturers' specifications, interviews with operators, and others, and theoretical modelling.

To estimate the usefulness of the various sensors in a small target detection role, the available information on their performance was used in a comparison with visual search sweep widths under average and severe east coast conditions.

Given the paucity of data on which to base sweep width calculations under Canadian east coast conditions, an experimental target detection program based on the USCG methodology has been proposed for Placentia Bay on the south coast of Newfoundland and the open ocean, preferably the Hibernia area. The targets should include a covered fibreglass lifeboat, an escape capsule, a high speed rescue craft, a canopied liferaft and a simulated PIW - all of which are possible targets in search and rescue operations of the east coast. The program should include visual and radar search, and should be carried out during the day and night. The targets should be with and without detection aids such as lights, heat packs, and radar reflectors. The objectives would be to extend the existing USCG dataset for sweep width calculations from sea state 2 to 3 or 4, and to verify radar performance modelling results for the same sea states.

SOMMAIRE

L'objet de la recherche a été l'évaluation des techniques connues de détection appliquées aux cibles de petites dimensions (C.P.D.) flottant à la surface de la mer. Deux études ont été financées parallèlement par le Centre de développement des transports: la première menée par NORDCO à Saint-Jean, Terre-Neuve, sur les systèmes, embarqués: la deuxième, objet du présent rapport, conduite par F.G. Bercha and Associates, également de Saint-Jean, sur les systèmes aéroportés.

Les C.P.D. sont définies comme ayant une longueur totale inférieure à 20 m et englobent les embarcations, les bouées, le matériel océanographique, les personnes à la mer (P.A.M.) et les épaves de toutes sortes. Des facteurs divers tels que forme, dimension, couleur, matériau et aides à la télédétection éventuellement transportées par les cibles ont été pris en compte. Pour analyser les performances des capteurs considérés, quatre cibles distinctes ont été caractérisées: des embarcations de 15 et de 7 m, un bateau pneumatique de sauvetage et une P.A.M. En outre, les chercheurs ont caractérisé les conditions climatiques moyennes (probabilité de dépassement de 50 p. 100) et difficiles (probabilité de 25 p. 100), à l'égard de secteurs géo-climatiques représentatifs de la région des Grands bancs. Les conditions climatiques moyennes correspondent généralement à des états de mer 2 ou 3 l'été et 4 ou 5 l'hiver. Les conditions difficiles correspondent à des états de mer 4 l'été et 5 ou 6 l'hiver, et il convient de rappeler que les glaces constituent un facteur supplémentaire à prendre en compte dans les secteurs septentrionaux durant les mois d'hiver et de printemps.

Les systèmes ayant fait l'objet de la présente recherche ont été: le capteur IR à balayage frontal, la télévision à faible niveau de luminosité et les radars aéroportés. Le principe fondamental de chacun des systèmes

est expliqué et les facteurs susceptibles de dégrader les performances ont été abordés. Quant à l'information sur l'aptitude des systèmes à détecter les objets visés, elle a été puisée à diverses sources: publications, notices des fabricants, interviews personnelles, notamment avec les opérateurs et, enfin, modélisation mathématique.

Afin de pouvoir évaluer l'aptitude des divers systèmes à détecter des C.P.D., une comparaison a été faite entre les systèmes de détection radar et la détection visuelle, sur le plan de la largeur des couloirs balayés dans les conditions climatiques précédemment définies.

Vu la pénurie d'information susceptible de permettre le calcul des largeurs de couloir dans les conditions climatiques de la côte Est du Canada, un programme expérimental fondé sur la méthodologie de la Garde côtière américaine a été proposé pour la détection de C.P.D. dans la baie Placentia, au sud de Terre-Neuve et en plein océan à Hibernia. Les cibles seraient un canot de sauvetage en fibres de verre, une capsule de sauvetage, une vedette de sauvetage rapide, un radeau de sauvetage avec tente et une P.A.M. simulée, autant de cibles qui pourraient un jour ou l'autre faire l'objet d'une opération de recherche et de sauvetage authentique, au large de la côte Est. Ce programme de recherche devrait porter sur la détection visuelle et la détection radar, tant de jour que de nuit, les cibles étant équipées ou non d'aides à la détection; sources de lumière, générateurs d'énergie thermique et réflecteurs radar. L'objectif de ce programme serait double: élargir la base de données rassemblée par la Garde côtière américaine de manière à étendre le calcul des largeurs à l'état de mer 3 ou 4 au lieu de 2 et vérifier les prévisions théoriques obtenues par modélisation concernant les performances des radars dans les mêmes conditions (états de mer).

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The proposed study entitled "Evaluation of the Technology for Detecting Small Objects at Sea: Elevated Sensor Platforms" is one of two parallel studies. The purpose of this program was to evaluate those sensors which can be mounted in airborne vehicles and determine their utility in small object detection. The parallel report was concerned with a similar evaluation using surface platforms as mounts for the sensors.[1] Both studies were closely coordinated to ensure that a common understanding of target types and environmental conditions were maintained throughout both reports.

The program was concerned with existing techniques and methodologies. If a technique was identified, but not a proven small object detection sensor, it was not considered. If the sensor was proven, but application to small object detection was not demonstrated, or demonstrated to not match the performance of other sensors, its evaluation was not pursued in great detail. One of the goals of the study was to determine if detection probabilities existed, or could be developed for use.

1.2 Scope of Work

The study was concerned with five principal tasks and a formal report. The first task was to define the environmental parameters. To accomplish this, the Grand Banks area was selected, based on the evaluators' previous operational experience in airborne iceberg reconnaissance programs for the oil industry. Environmental data for the Grand Banks was then collected and assessed to ensure that the extreme conditions necessary to define performance limits would be possible. This information is contained in Section 2.1.

[1] TP6818E Evaluation of the Technology for Detecting Small Objects at Sea: Surface Sensor Platforms. Prepared for Transportation Development Centre by Nordco Ltd., September 1985.

The second task was the selection and characterization of target size/classes. These are clarified in Section 2.2. An initial preliminary classification was made that subsequently showed agreement with previous work identified in the literature.

Task 3 was the major task of the study. It involved a literature search to identify data concerned with sensors and their use in small object detection. Extensive searches were carried out using computerized literature data bases. It was evident during this search that the main body of work in small object detection has been, and is being, carried out by the United States Coast Guard (U.S.C.G). In addition, the Search and Rescue Manual used in Canada is derived from the U.S.C.G. Manual. This manual covers all aspects of search and rescue operations. The most important concepts pertaining to this evaluation are contained in Section 2.3.

Chapter 3 provides details concerned with the literature review, sensor information and probability-of-detection data. Chapter 4 discusses the detection probability data and identifies the candidate sensor systems for Canadian trials (Task 4). A preliminary experimental plan from which a detailed plan could be derived (Task 5) is introduced in Chapter 5.

This evaluation report satisfies the reporting requirements of the study. Chapter 6 outlines conclusions and recommendations based on the evaluation.

1.3 Acknowledgements

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- D.N.D. - S.A.R.
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- N.O.R.D.C.O. (parallel study).

CHAPTER 2

ENVIRONMENTAL DATA, TARGET INFORMATION, AND SEARCH AND RESCUE CONCEPTS

2.1 Environmental Data

The east coast of Canada can be divided into several subregions, each characterized by local meteorological and oceanographic conditions. This subdivision would be appropriate if the search areas were small, but because this study is concerned with airborne and spaceborne detection systems, it was decided that the environmental extremes that characterize the Grand Banks, offshore Newfoundland would be the most suitable. The full range of environmental conditions that occur in this area represents the extremes that would be encountered in most marine areas and are thus suitable for sensor detection evaluation. Although the results of the evaluation should be applicable to most Canadian waters, only east coast environmental data were used.

2.1.1 Sea Surface Temperatures

2.1.1.1 Historical Data

The full range of sea surface temperatures for the Grand Banks from 1975 to 1984 is given in Table 2.1 and illustrated graphically in Figure 2.1. This is supplemented by Table 2.2, which gives data for 1910 to 1984. The reported temperatures are actually for water depths from 0 to 1 m. The actual observation areas differ somewhat, but the area denoted in Figure 2.1 represents the general area where measurements were taken. The readings across the area indicate the coldest water to be nearest the surface and nearest the shore (Markham, 1980). The colder water is associated with the Labrador Current and the warmer with off-shelf locations. The data were obtained from ships of opportunity, scientific vessels and exploration rigs. The coldest temperatures occur during the period from January to April, and the warmest from July to September. The mean annual temperature was 5.7°C. Figure 2.2 gives the air-sea temperature difference for the period from 1975 to 1984.

TABLE 2.1

SEA SURFACE TEMPERATURE DISTRIBUTION STATISTICS FOR THE GRAND BANKS, 1975 - 1984

[Canadian Climate Centre]

MONTH	MEAN (°C)	STANDARD DEVIATION	MAXIMUM (°C)	MINIMUM (°C)	NUMBER OF OBSERVATIONS
January	1.0	1.4	12.0	-2.7	2 957
February	0.3	1.4	14.0	-2.8	2 415
March	0.4	1.2	9.0	-2.6	2 230
April	1.2	1.4	11.6	-2.7	3 133
May	3.5	1.8	16.1	-1.5	4 202
June	6.4	2.2	18.0	-2.7	3 515
July	10.8	2.6	23.0	-0.2	2 933
August	13.8	2.0	22.0	1.5	2 836
September	12.6	2.1	21.3	0.0	2 502
October	9.5	2.5	19.0	-0.2	2 761
November	6.0	2.2	30.0	-2.2	2 826
December	2.9	2.2	14.0	-2.0	2 948

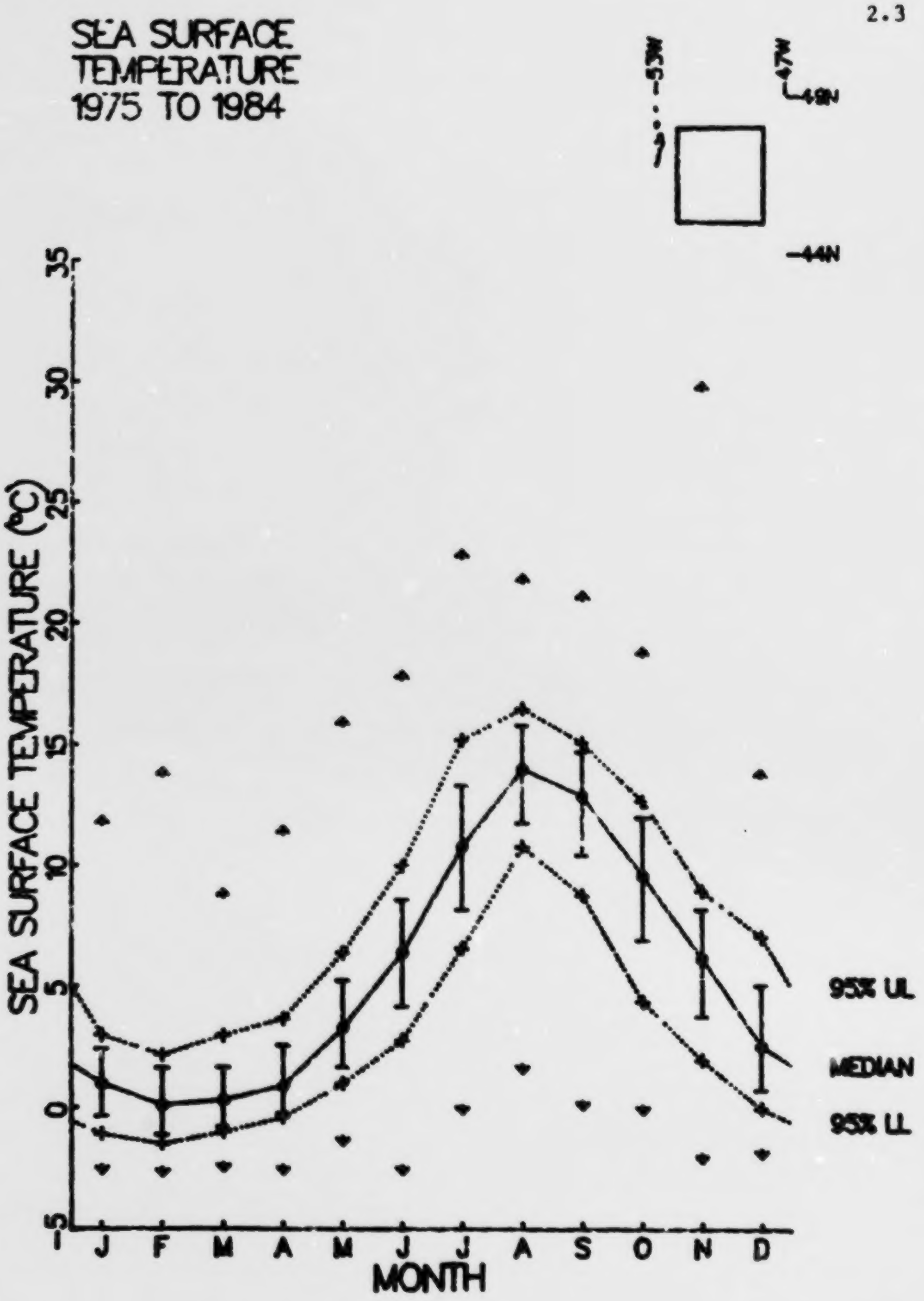


FIGURE 2.1 SEA SURFACE TEMPERATURE, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

TABLE 2.2

SEA SURFACE TEMPERATURE DISTRIBUTION STATISTICS FOR THE GRAND BANKS, 1910 - 1984

[Marine Environmental Data Service]

MONTH	AVERAGE (°C)	STANDARD DEVIATION	MAXIMUM (°C)	MINIMUM (°C)	NUMBER OF OBSERVATIONS
January	0.64	0.85	1.90	-1.74	35
February	0.53	0.55	1.70	-0.80	47
March	0.19	0.75	2.90	-1.45	58
April	0.28	1.03	6.50	-1.40	253
May	2.06	1.49	5.99	-0.95	537
June	4.84	2.06	14.36	1.10	567
July	10.33	1.80	14.28	5.60	245
August	12.61	1.80	17.60	6.37	119
September	12.06	2.64	18.30	0.30	66
October	8.54	1.83	12.80	2.80	169
November	4.91	2.03	12.90	1.00	114
December	2.31	2.24	4.82	0.50	3

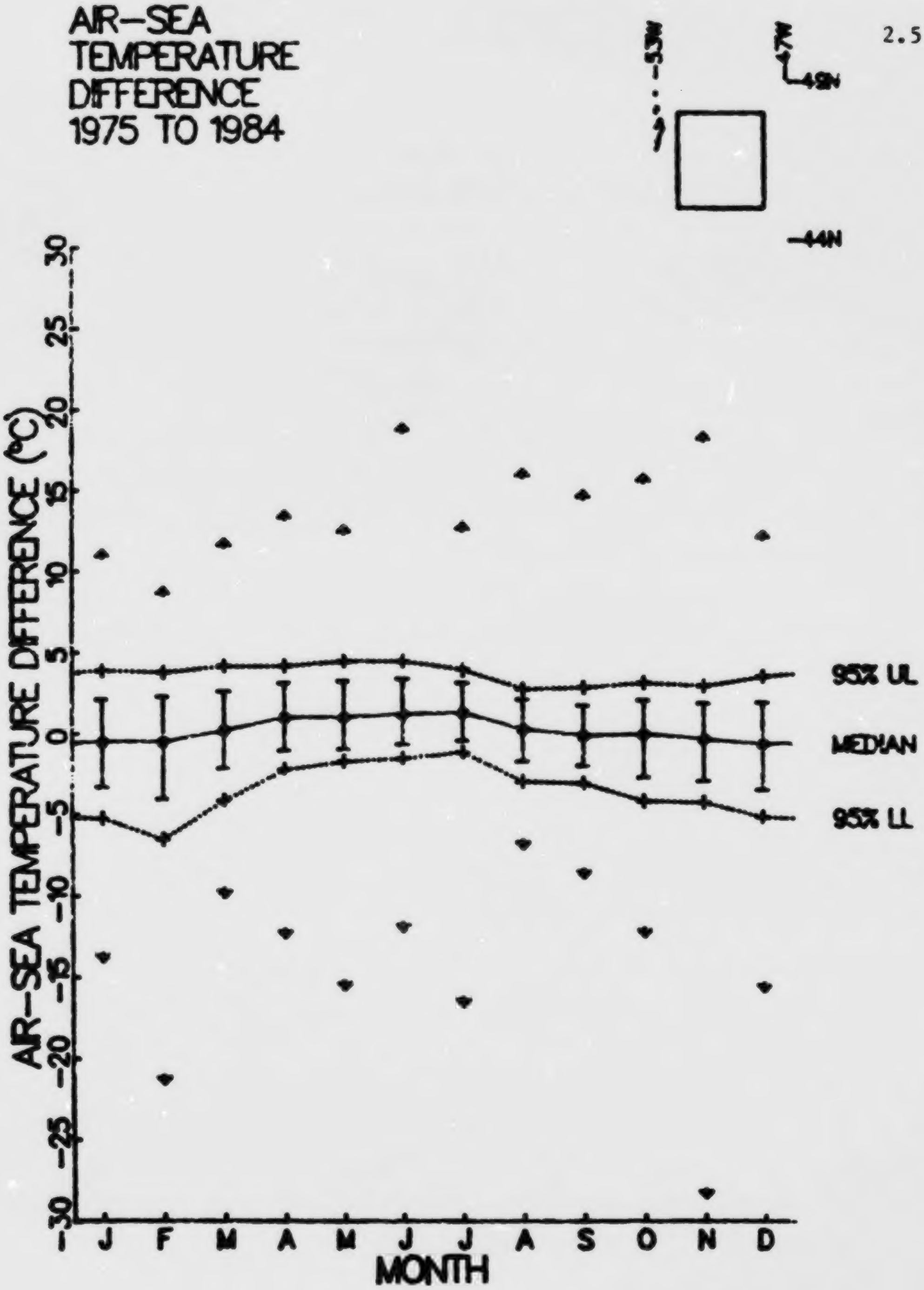


FIGURE 2.2 AIR-SEA TEMPERATURE DIFFERENCE, 1975 TO 1984 (CANADIAN CLIMATE CENTRE)

2.1.1.2 Pertinent Evaluation Data

Sea surface temperature data is most important with respect to infrared and visual detection sensors. The infrared sensors measure temperature differences and the visual ocean features related to biologic activity associated with upwellings and eddies. The maximum recorded temperature range was from -2.8°C to 30°C, while the average temperature range was from 0.3°C to 13.8°C. Based on these data, an expected range would be from -1.8°C (ice formation) to 25°C. This range is measureable with all state-of-art infrared systems; thus, no problems should occur with recording the temperature of the ocean background. The air-sea temperature differences indicate that the range is great enough that temperature cross-over (the point at which air temperature and sea temperature are the same) will be a random occurrence. The 95% limits indicate the difference will normally be about 8°, with June and July, the 'fog' months experiencing the smallest difference range.

2.1.2 Wave Heights

2.1.2.1 Historical Data

Wave data can be given in various forms. Figures 2.3, 2.4 and 2.5 present, respectively, the wave height, swell height, and combined wave height, which is a combination of wave and swell height. The data covers the period from 1915 to 1984 and shows the median measure, the 95% upper limit measure and the extreme measure. Table 2.3 shows the most frequent direction, median and maximum wave height, and median, maximum and minimum wave period. Table 2.4 shows the same data in terms of swell. The data show that the most common wave height (32% of the time) is 2 to 3 m, and that the most active seas occur in January and February. The calmest seas occur in June. Ninety percent of the time wave heights vary between 1 and 5 m. Waves are typically from the SW or W, while swells are generally from the SW or N. Wave period maximum and minimum values occur in February. It can be seen that February and March are the worst months on the Grand Banks in terms of wave climate. Table 2.5 shows wave height data, and Table 2.6, wave periods from different sources. These data show wave height and period in terms of percent occurrence.

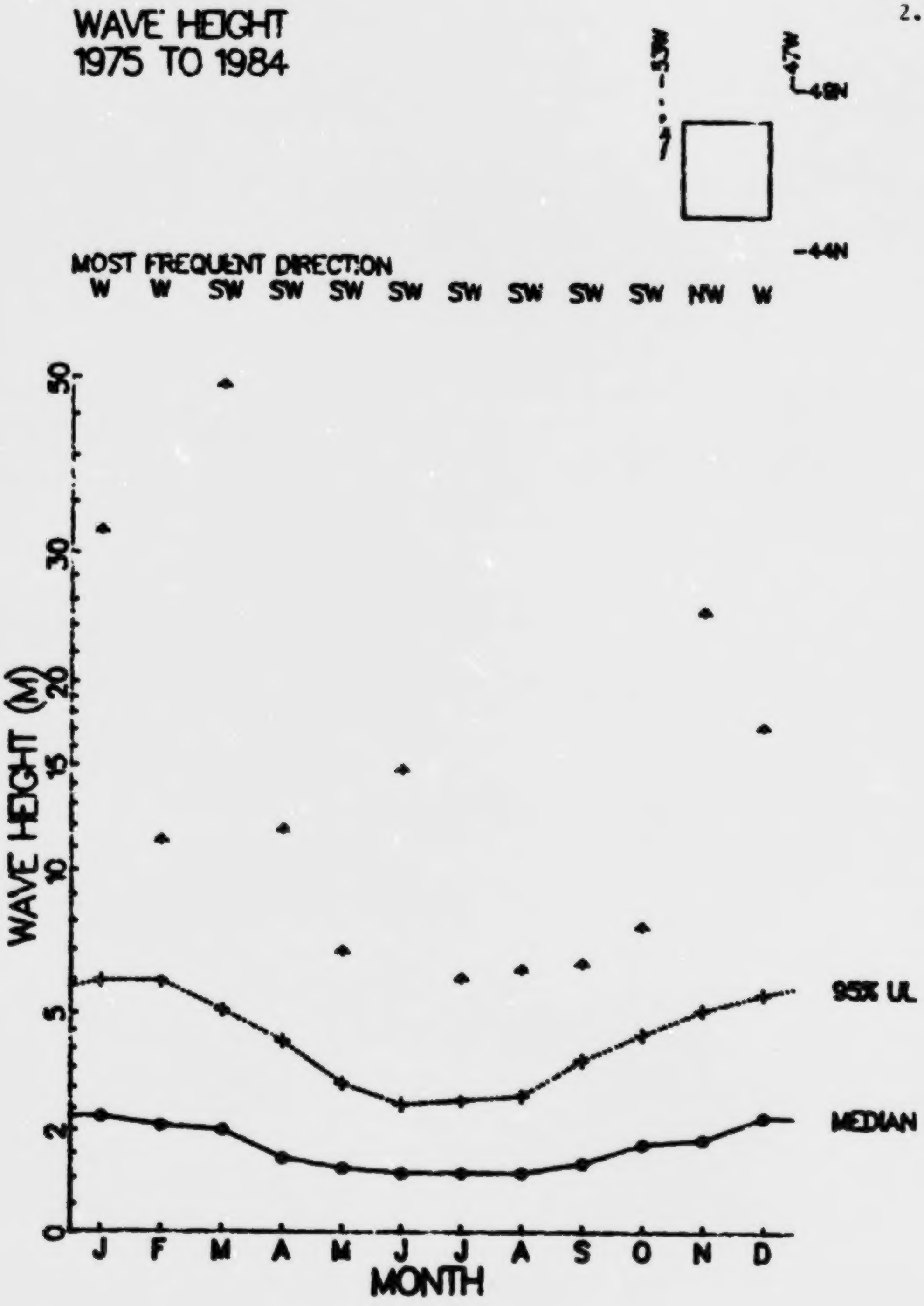


FIGURE 2.3 WAVE HEIGHT, 1975 TO 1984
(CANADIAN CLIMATE CENTRE)

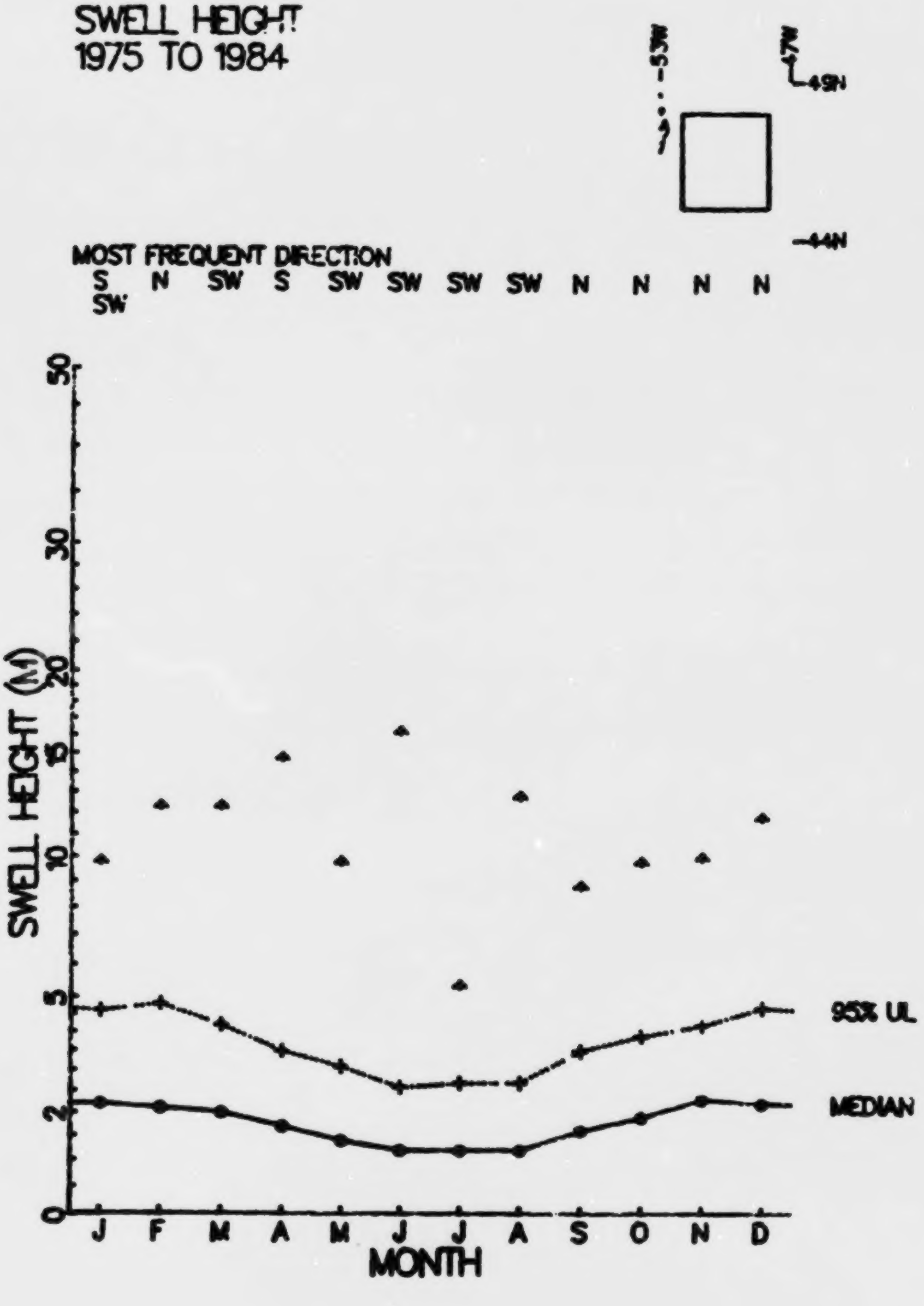


FIGURE 2.4 SWELL HEIGHT, 1975 TO 1984
(CANADIAN CLIMATE CENTRE)

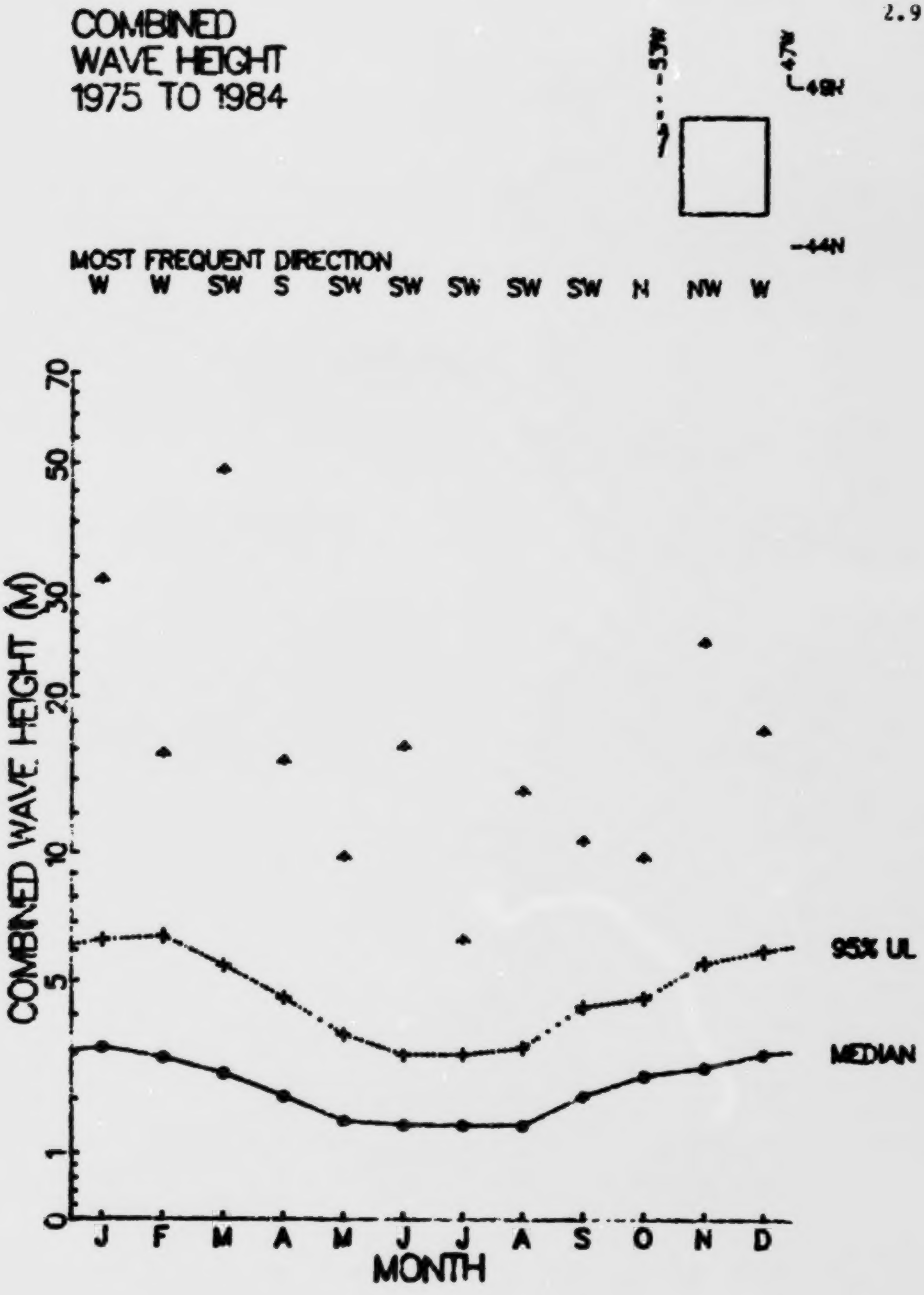


FIGURE 2.5 COMBINED WAVE HEIGHT, 1975 TO 1984
(CANADIAN CLIMATE CENTRE)

TABLE 2.3

OCEAN WAVE DATA: GRAND BANKS, 1975 - 1984
[Canadian Climate Centre]

MONTH	MOST FREQUENT DIRECTION	WAVE HEIGHT (m)			WAVE PERIOD (sec.)			
		Median	Maximum	No. of Observations	Median	Maximum	Minimum	No. of Observations
January	W	2.3	32.5	2 915	6	14	5	2 843
February	W	2.1	11.5	2 389	6	14	5	2 320
March	SW	2.0	49.5	2 127	6	21	5	2 085
April	SW	1.4	12.0	2 960	5	29	5	2 811
May	SW	1.2	7.1	3 951	5	21	5	3 703
June	SW	1.1	15.0	3 245	5	14	5	3 059
July	SW	1.1	6.2	2 695	5	21	5	2 562
August	SW	1.1	6.5	2 688	5	12	5	2 565
September	SW	1.3	6.7	2 454	5	16	5	2 370
October	SW	1.7	8.0	2 635	6	12	5	2 538
November	NW	1.8	25.5	2 696	5	21	5	2 668
December	W	2.3	17.5	2 973	6	21	5	2 974

TABLE 2.4

OCEAN SWELL DATA: GRAND BANKS, 1975 - 1984
[Canadian Climate Centre]

MONTH	MOST FREQUENT DIRECTION	SWELL HEIGHT (m)			SWELL PERIOD (sec.)			
		Median	Maximum	No. of Observations	Median	Maximum	Minimum	No. of Observations
January	SW/S	2.2	10.0	1 765	9	14	5	1 710
February	N	2.1	12.5	1 476	9	14	5	1 400
March	SW	2.0	12.5	1 156	9	14	5	1 078
April	S	1.7	15.0	1 615	9	14	5	1 437
May	SW	1.4	10.0	2 223	9	14	5	1 817
June	SW	1.2	16.5	1 865	9	14	5	1 605
July	SW	1.2	5.5	1 373	9	14	5	1 285
August	SW	1.2	13.0	1 414	9	14	5	1 320
September	N	1.6	9.0	1 593	9	14	5	1 508
October	N	1.9	10.0	1 613	9	14	5	1 552
November	N	2.3	10.2	1 812	9	14	5	1 753
December	N	2.2	12.0	1 720	10	14	5	1 673

TABLE 2.5

WAVE HEIGHT DATA FROM "MEDS" STATIONS, 1973 - 1983
(PERCENT)
(MARINE ENVIRONMENTAL DATA SERVICE)

WAVE HEIGHT (m)	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
13 - 14													
12 - 13		0.3											0.03
11 - 12		0.5											0.04
10 - 11	0.4	0.5								0.1			0.08
9 - 10	0.6	0.5								0.1	0.4		0.13
8 - 9	1.4	1.5							0.1	0.2	0.3	0.5	0.33
7 - 8	3.8	3.0	0.3	0.4					0.5	0.3	0.7	1.9	1.43
6 - 7	5.8	5.2	7.6	0.9				0.1	0.5	1.6	2.0	4.4	2.42
5 - 6	8.7	9.1	14.3	2.4				0.4	1.9	4.5	7.8	8.9	4.83
4 - 5	18.8	13.6	12.7	6.3	0.7		2.2	1.8	4.0	10.6	17.3	17.3	8.78
3 - 4	30.5	19.5	33.0	22.7	13.3	2.5	5.7	6.7	19.0	24.0	29.9	38.9	20.48
2 - 3	25.0	32.1	29.8	47.4	29.5	27.6	22.7	28.7	43.0	41.6	33.5	25.5	32.20
1 - 2	5.0	9.9	2.2	19.9	53.0	68.3	62.2	57.4	30.4	17.1	7.8	2.7	28.00
0 - 1	0.0	4.4	0.0	0.0	3.5	1.6	7.1	4.9	0.3	0.1	0.3	0.0	1.85

* Maximum recorded wave height = > 12 m in February.
Average Seas: 2 - 3 m, present in all months.

TABLE 2.6

WAVE PERIODICITY FROM "MEDS" STATIONS, 1973 - 1983
(MARINE ENVIRONMENTAL DATA SERVICE)

WAVE HEIGHT (m)	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
2 - 3		2.2											0.18
3 - 4		0.2					0.6	0.2	0.1		0.1		0.1
4 - 5		1.0	0.3		0.9	1.7	2.2	2.2	0.5	0.5	0.3		0.8
5 - 6	1.2	1.7	1.3	1.1	3.0	6.1	7.3	9.5	2.3	2.1	1.4	0.8	3.15
6 - 7	3.5	3.2	1.6	4.8	4.6	11.0	12.7	16.1	6.0	4.6	2.7	2.3	5.18
7 - 8	2.9	5.7	3.5	7.8	7.2	10.1	16.4	18.3	10.5	6.6	4.0	3.4	8.37
8 - 9	7.0	7.7	11.1	14.5	20.5	26.9	22.6	23.6	16.8	14.2	7.4	6.2	14.88
9 - 10	20.4	17.3	13.7	32.7	30.9	22.7	24.8	17.1	23.5	21.7	20.4	20.8	22.17
10 - 11	13.6	13.3	20.3	13.4	9.0	6.3	7.2	5.4	13.2	11.7	18.9	19.5	12.65
11 - 12	19.2	15.1	22.5	11.7	11.0	5.5	4.0	4.3	14.4	12.8	20.4	16.9	13.15
12 - 13	16.3	14.1	19.0	7.8	7.1	3.1	1.6	2.6	9.6	11.4	15.0	16.3	10.33
13 - 14	9.5	8.9		5.6	3.7	1.6	0.4	0.6	2.5	10.3	5.8	9.4	4.86
14 - 15			6.3									0.0	0.53
15 - 16	5.0	7.2		0.6	2.1	0.7		0.1	0.6	3.6	2.8	3.7	2.20
16 - 17			0.3										0.25
17 - 18	1.5	0.7				0.1		0.1		0.4	0.7	0.7	1.48
18 - 19													0.00
19 - 20		1.7				0.1							0.15

* Maximum range in February.
Most frequent periodocity: 9 - 10 sec.

2.1.2.2 Pertinent Evaluation Data

The MEDS data shows that most-expected wave heights in the evaluation areas are 2 to 4 m, with the majority of the waves being, on the average, 2 to 3 m. Wave heights are basically the highest during the winter and autumn storm seasons, as substantiated by data from the Canadian Climate Centre, with the highest percentage of higher waves occurring during February. During the period from November through March, waves greater than 5 m occur with some frequency. For the purposes of this report, extreme wave heights are those that exceed 10 m. This represents an upper limit for any evaluation. As the majority of waves are in the 2 to 4 m range, this evaluation will consider this the intermediate zone. Therefore, the three general wave classes for this study were identified as follows:

1) 0 to 2 m (calm seas).
2) 2 to 4 m (moderate seas).
3) 4 to 10 m (rough seas).

2.1.3 Wind Speed and Direction

2.1.3.1 Historical Data

Figure 2.6 gives a monthly summary of wind speed for the period from 1975 to 1984, including median wind speed, the upper and lower 95% limits, the extreme wind speed and most frequent direction. Figures 2.7 to 2.18 show the individual monthly wind speed exceedance data for the above period. Figure 2.19 is a plot of wind speed exceedance by month for 10, 20, 30, 40 and 50 kt winds. These data show that there is always a possibility of 50 kt winds and that at least 10% of the time, wind speed will exceed 30 kts. Figures 2.20 to 2.31 show the frequency of wind speed by direction. This elaborates on the data presented in Figure 2.6. The information shows wind speed by percent and direction. The prevailing wind directions are W and SW, for most of the year. Table 2.7 gives wind data for the period up to 1974, and basically confirms the 1975 to 1984 data. These data are from a U.S. source and show more variation in the resultant wind vector than do the Canadian data, although the westerly trend is still evident. The maximum wind speeds occur from December to February. The maximum average wind speeds, 19 kts, occur in January, and the lowest, 10.1 kts, in July.

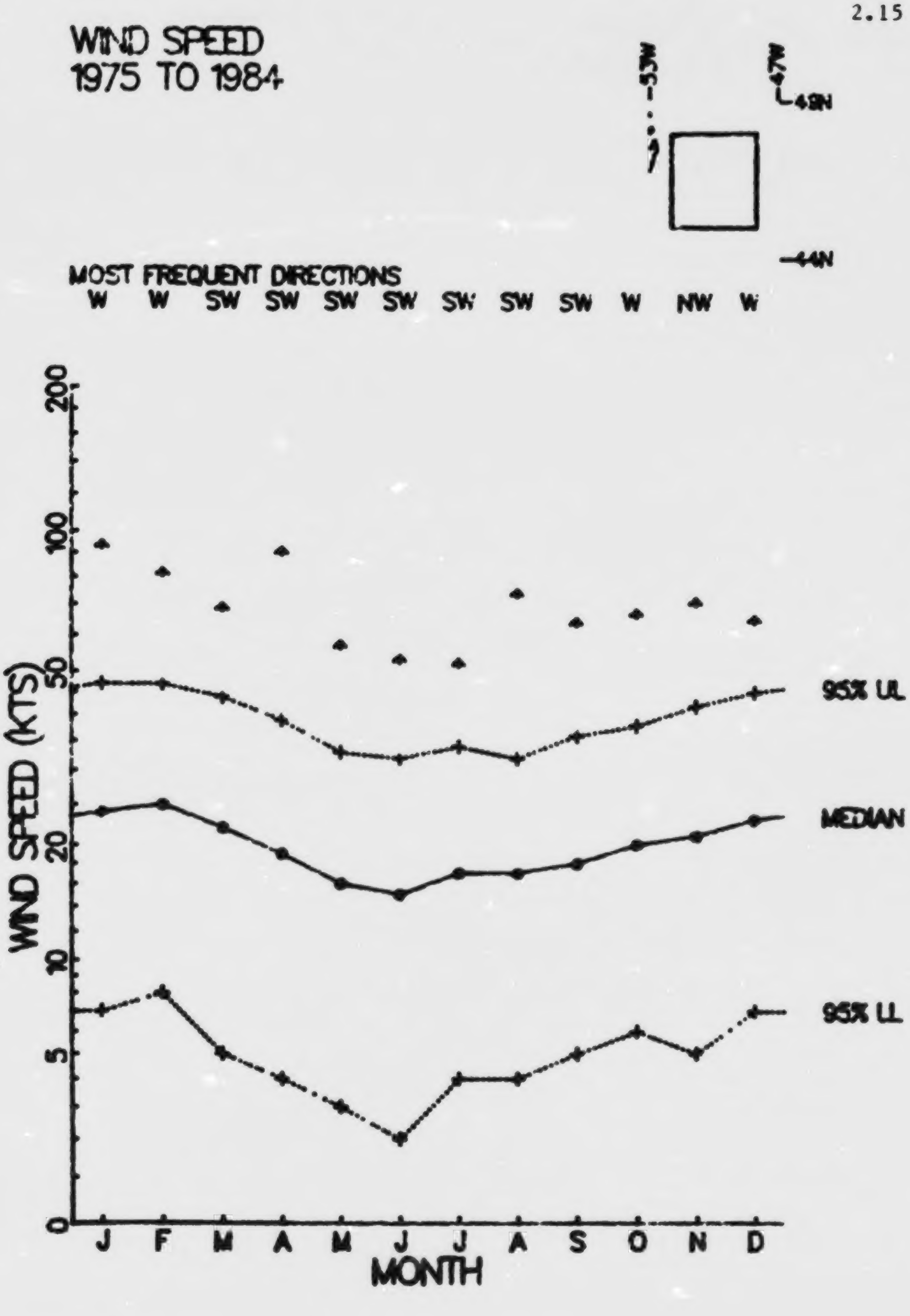


FIGURE 2.6 WIND SPEED, 1975 TO 1984
(CANADIAN CLIMATE CENTRE)

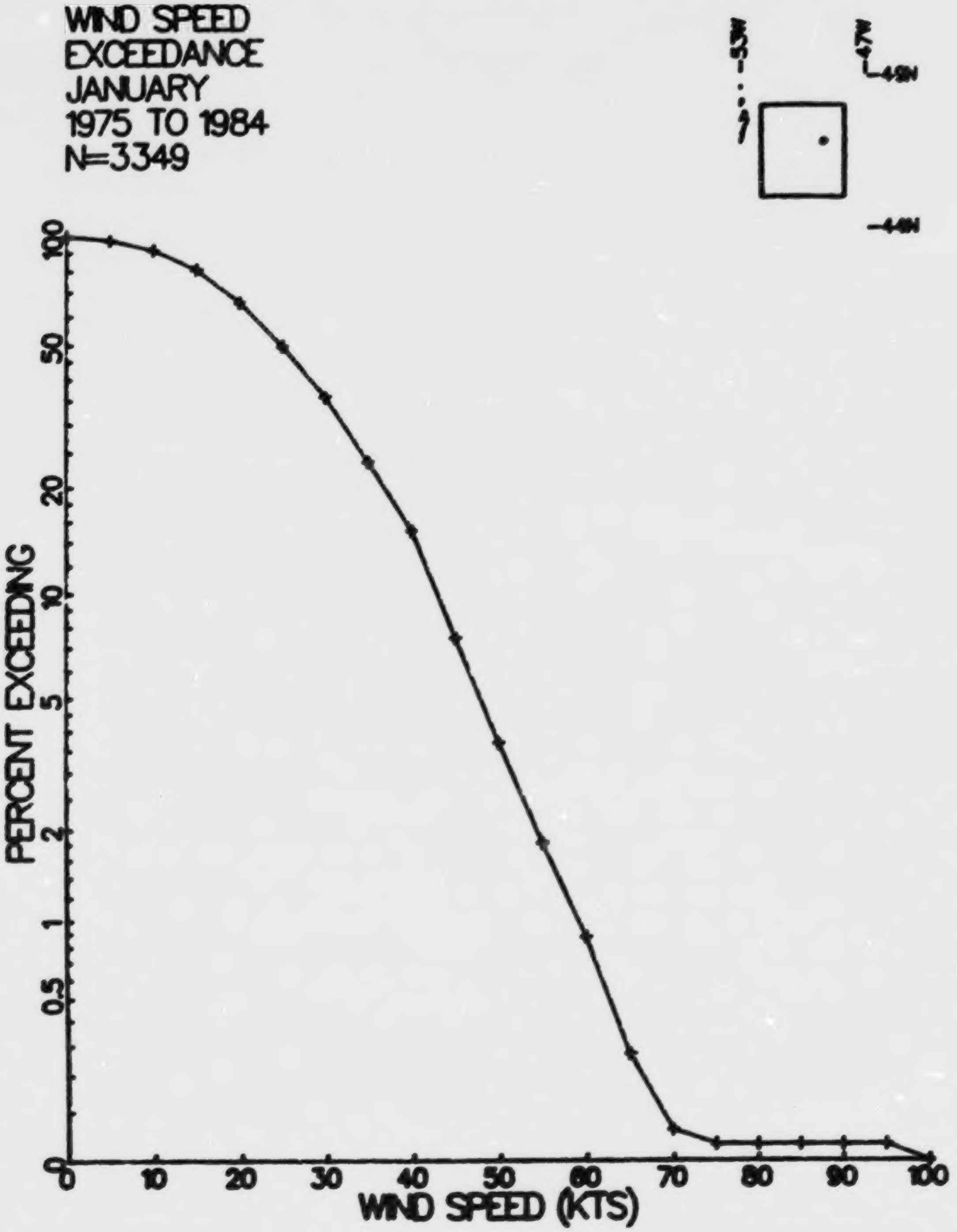


FIGURE 2.7 WIND SPEED EXCEEDANCE, JANUARY 1975 TO 1984
(CANADIAN CLIMATE CENTRE)

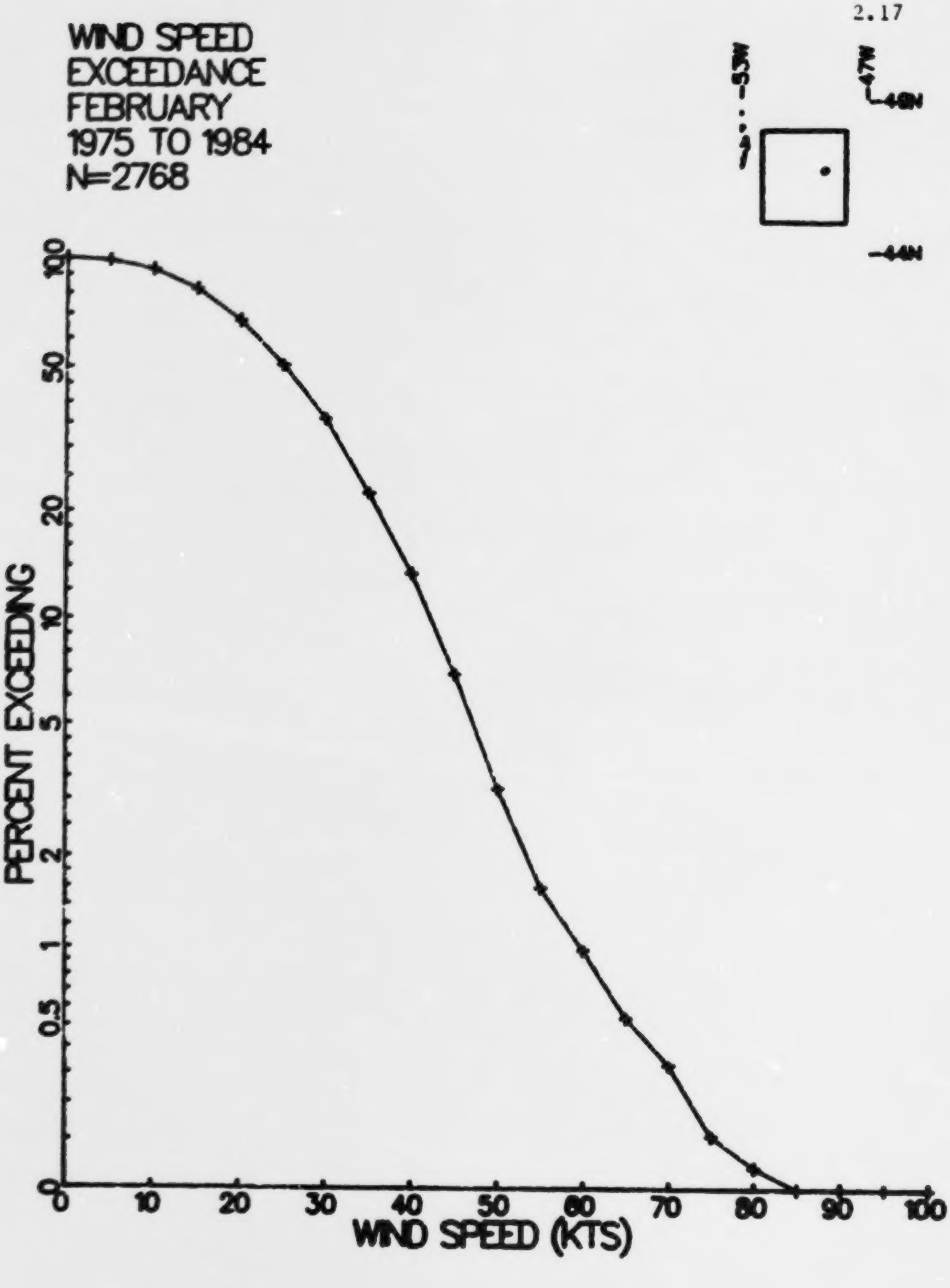


FIGURE 2.8 WIND SPEED EXCEEDANCE, FEBRUARY 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

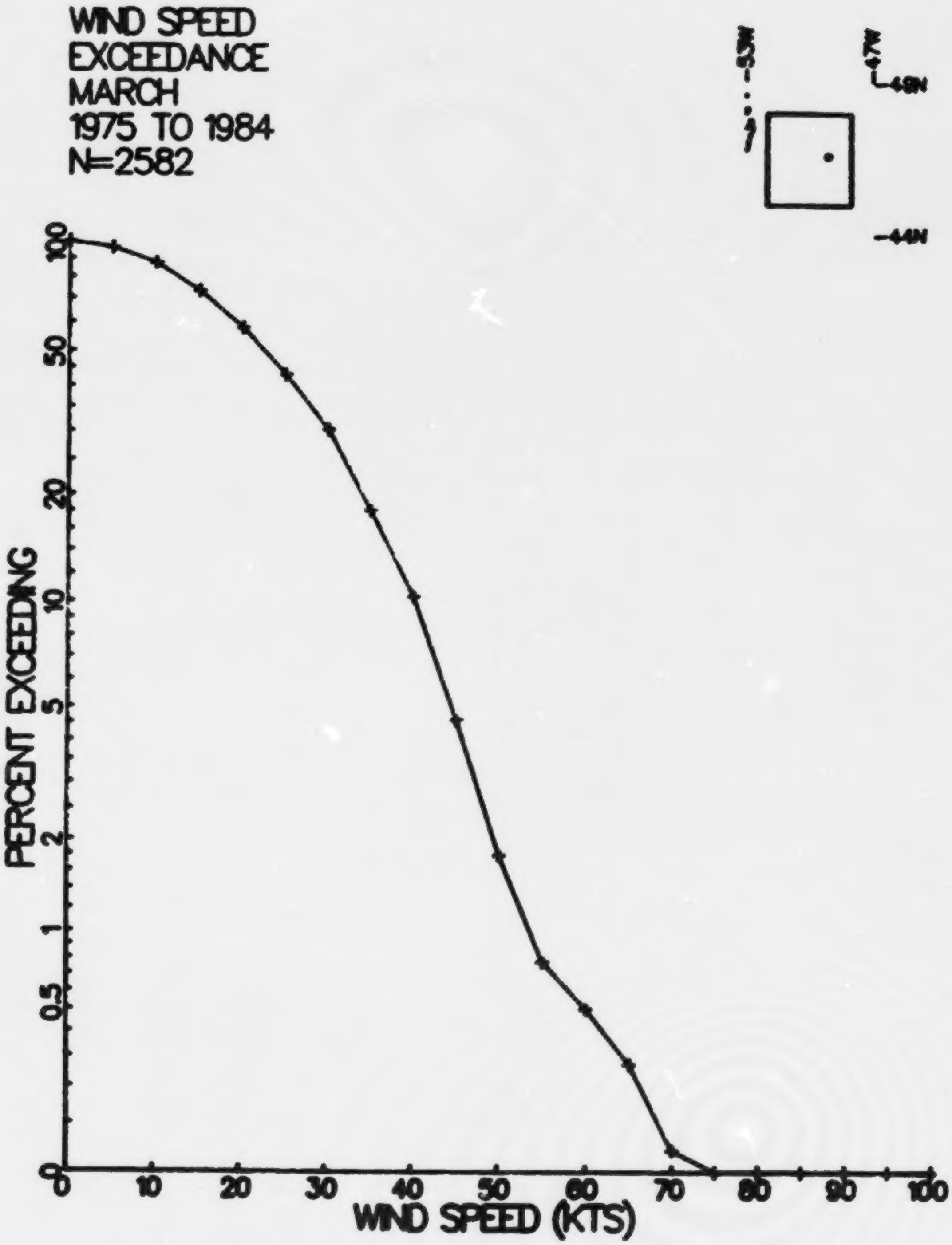


FIGURE 2.9 WIND SPEED EXCEEDANCE, MARCH 1975 TO 1984
(CANADIAN CLIMATE CENTRE)

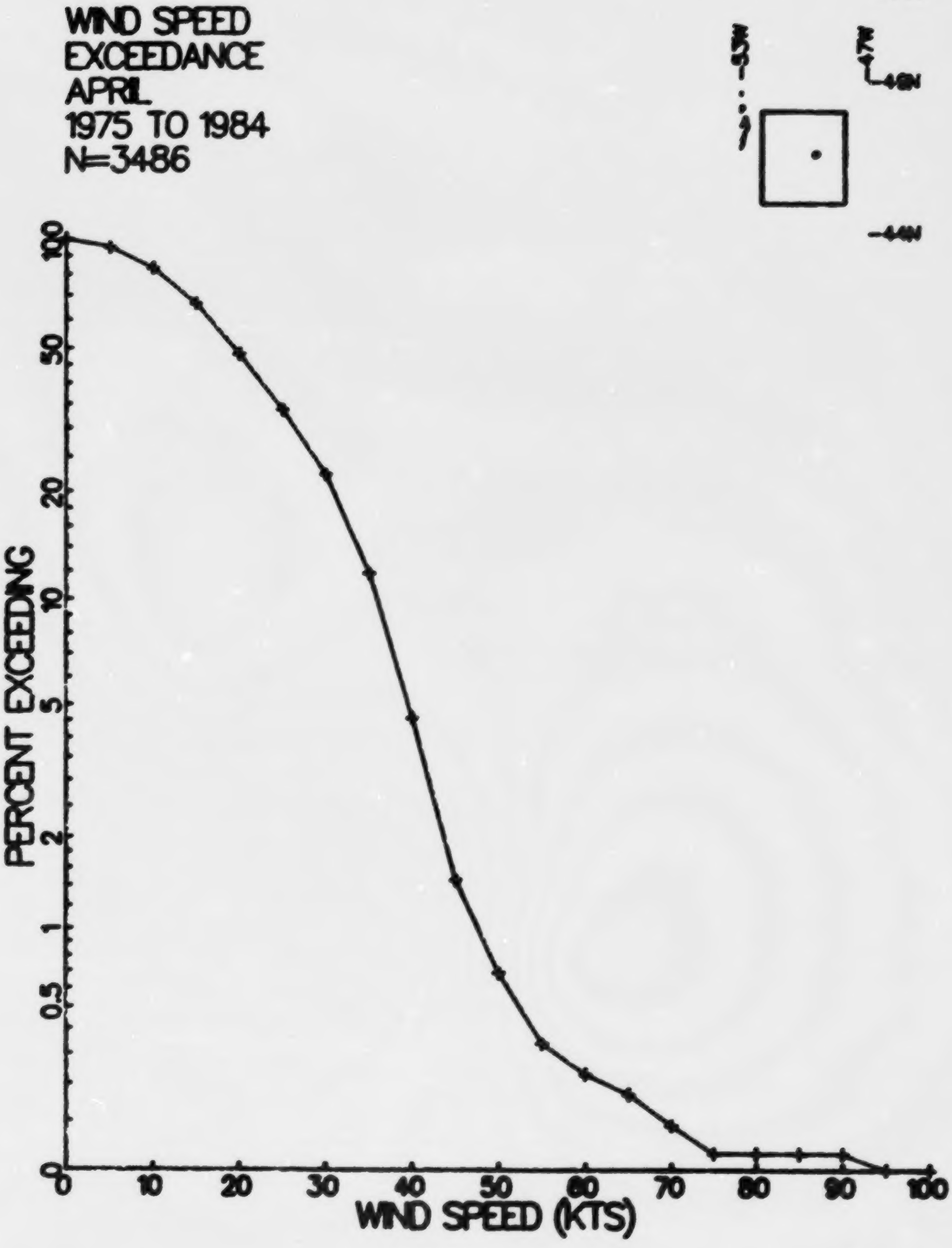


FIGURE 2.10 WIND SPEED EXCEEDANCE, APRIL 1975 TO 1984 (CANADIAN CLIMATE CENTRE)

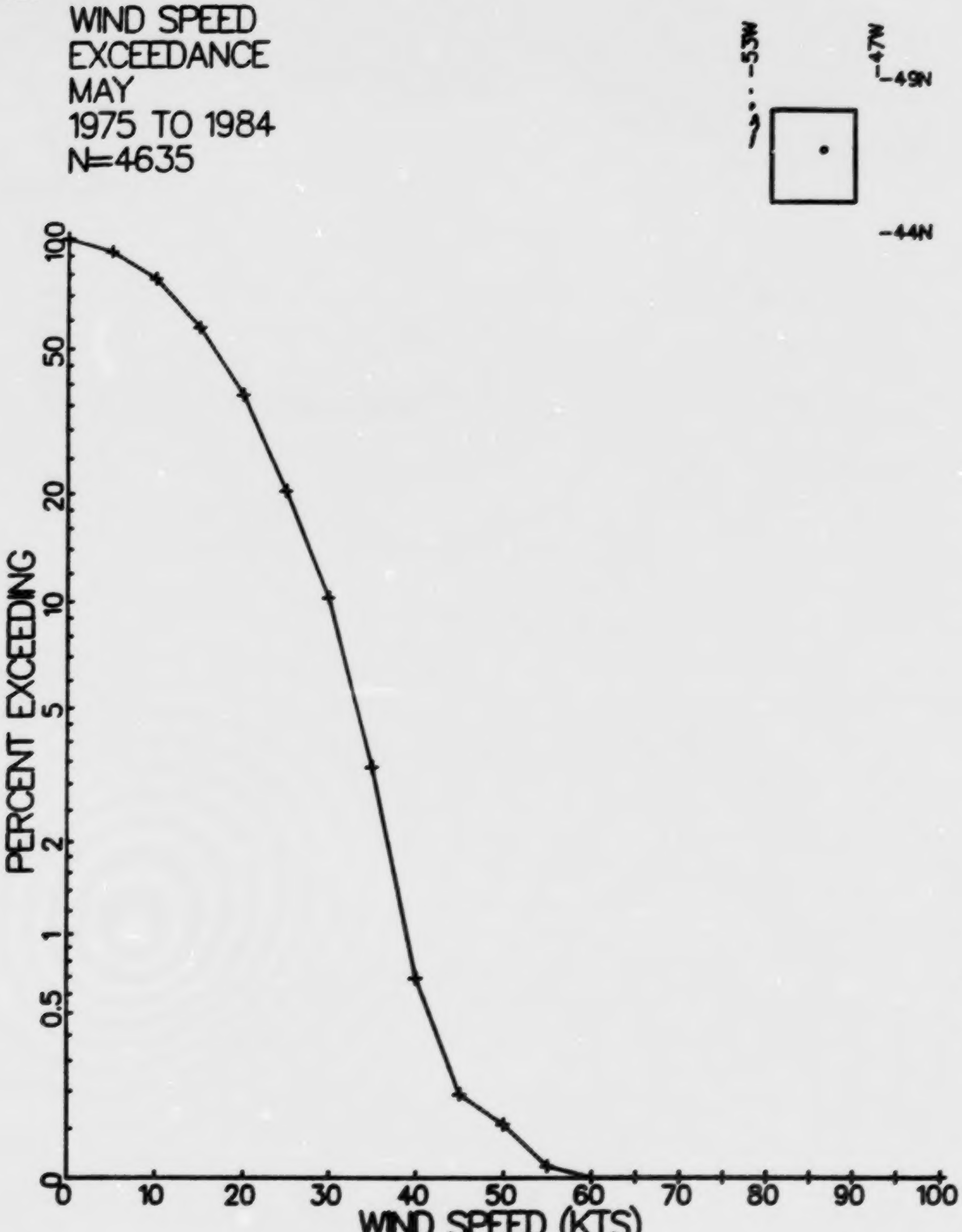


FIGURE 2.11 WIND SPEED EXCEEDANCE, MAY 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

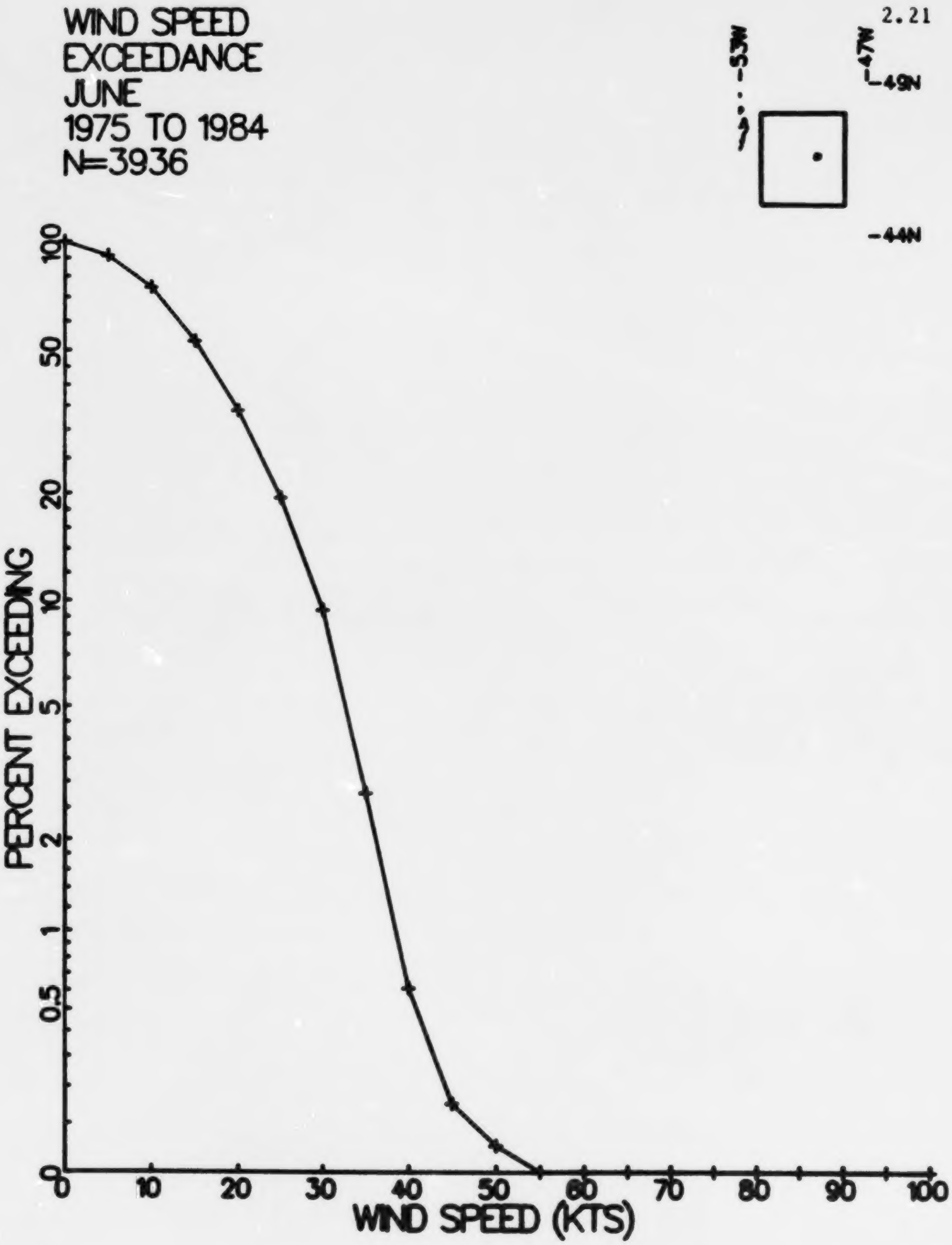


FIGURE 2.12 WIND SPEED EXCEEDANCE, JUNE 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

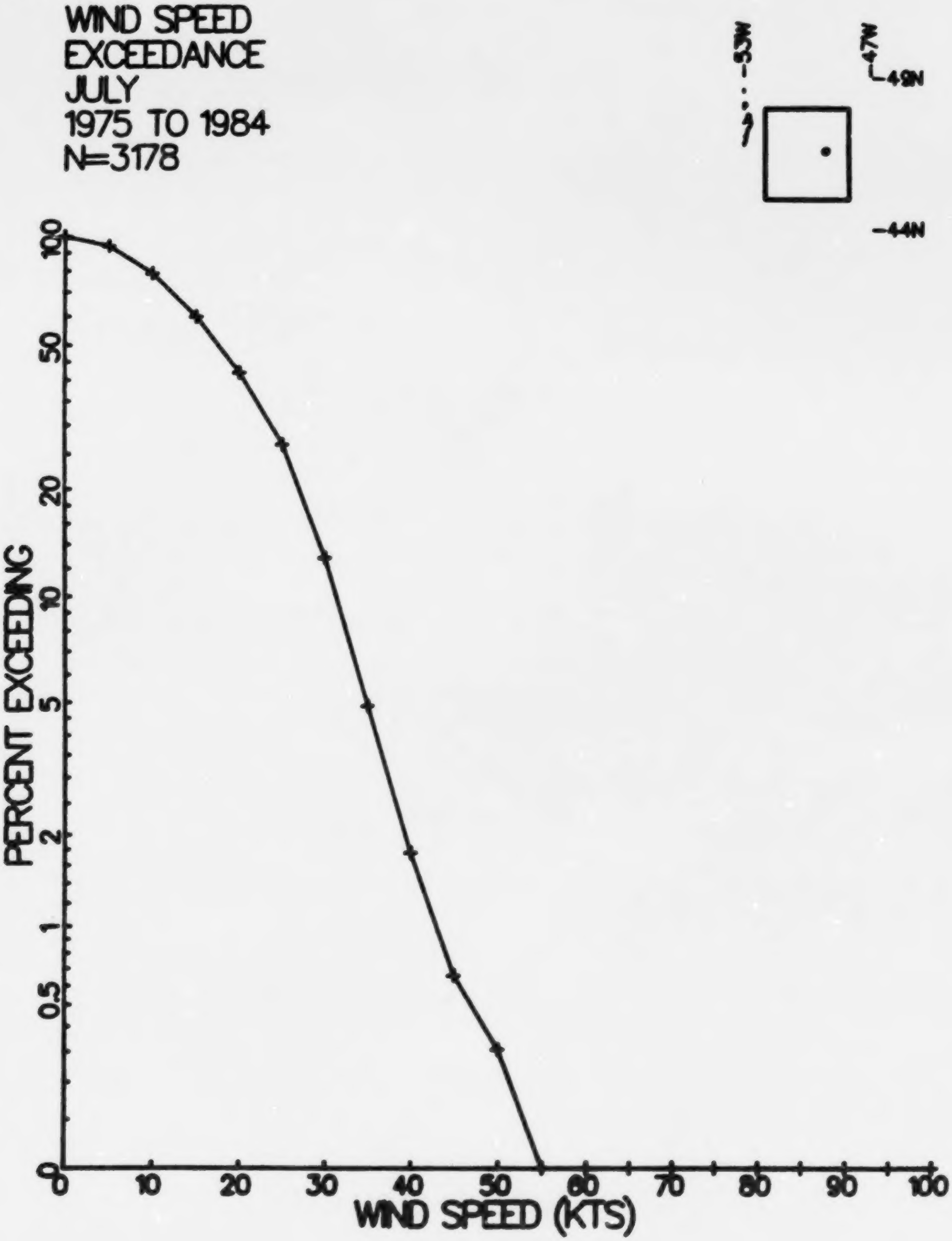


FIGURE 2.13 WIND SPEED EXCEEDANCE, JULY 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

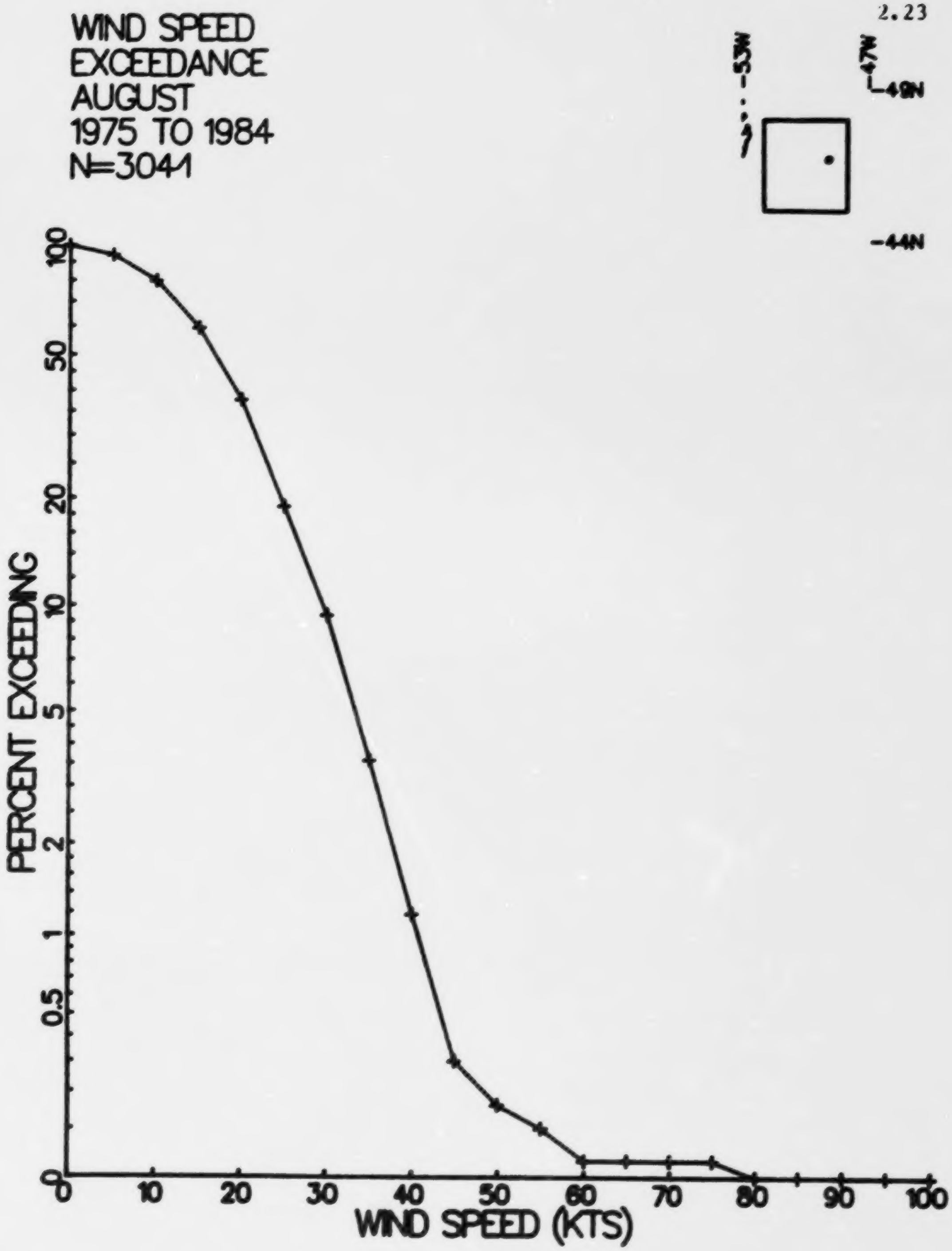


FIGURE 2.14 WIND SPEED EXCEEDANCE, AUGUST 1975 TO 1984 (CANADIAN CLIMATE CENTRE)

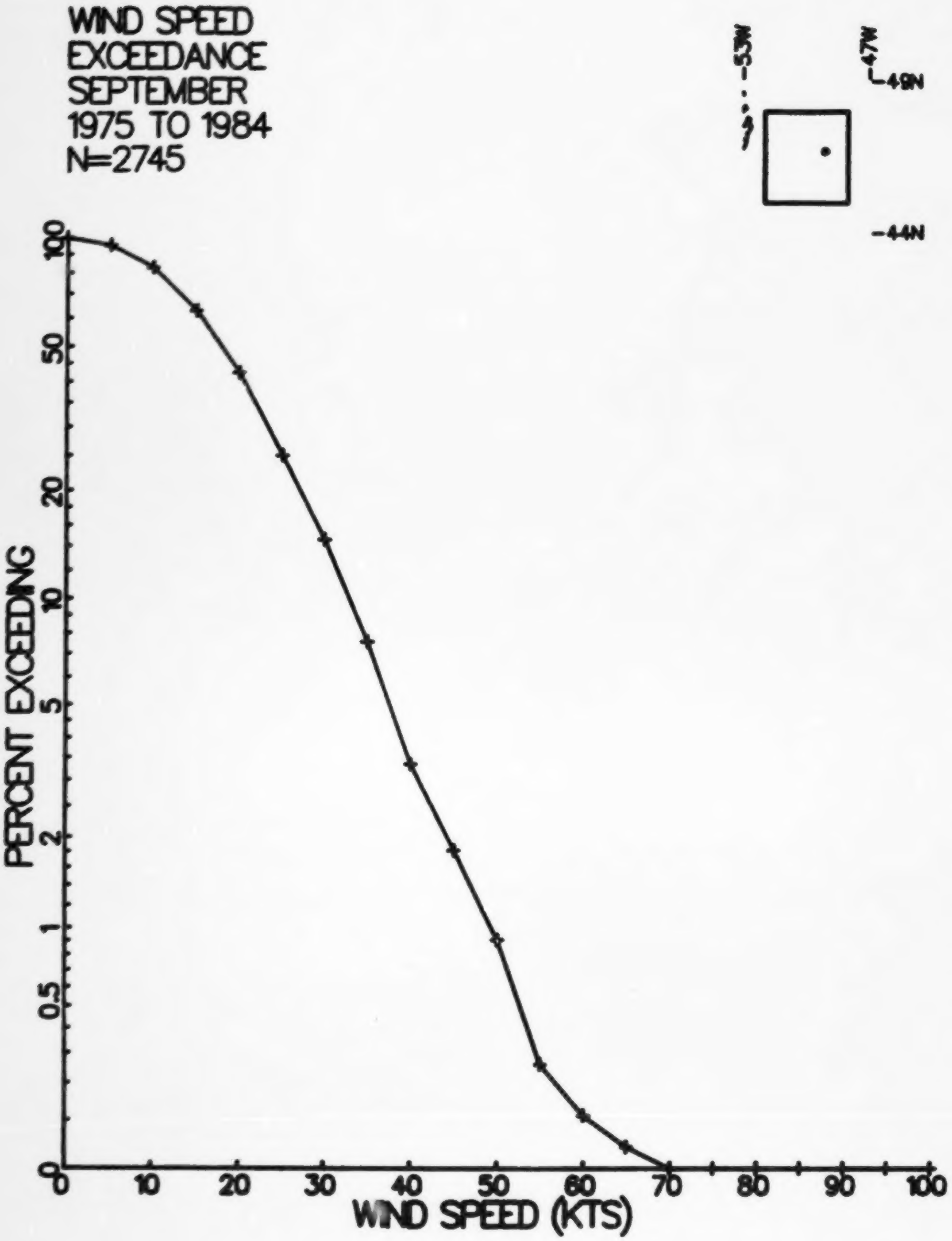


FIGURE 2.15 WIND SPEED EXCEEDANCE, SEPTEMBER 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

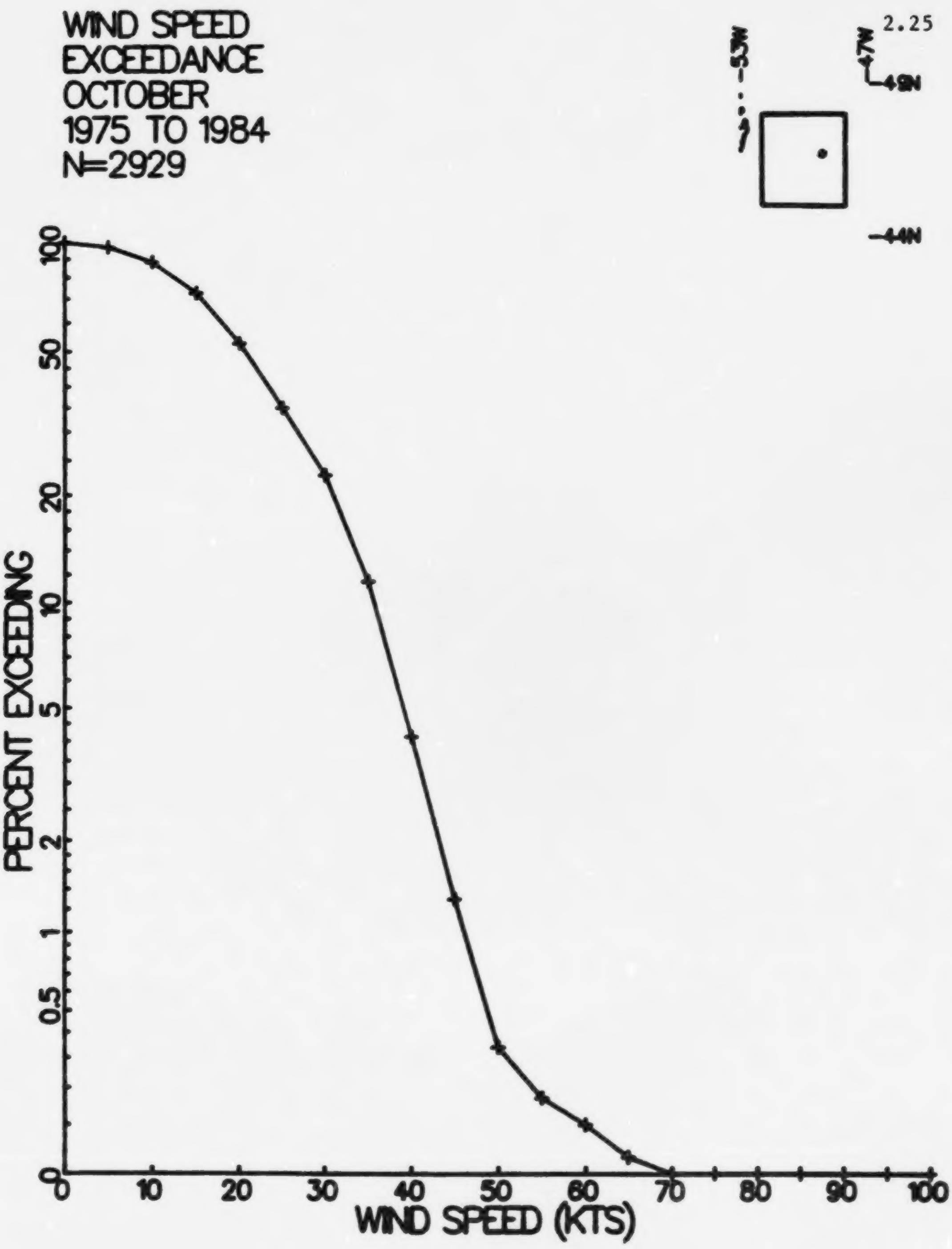


FIGURE 2.16 WIND SPEED EXCEEDANCE, OCTOBER 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

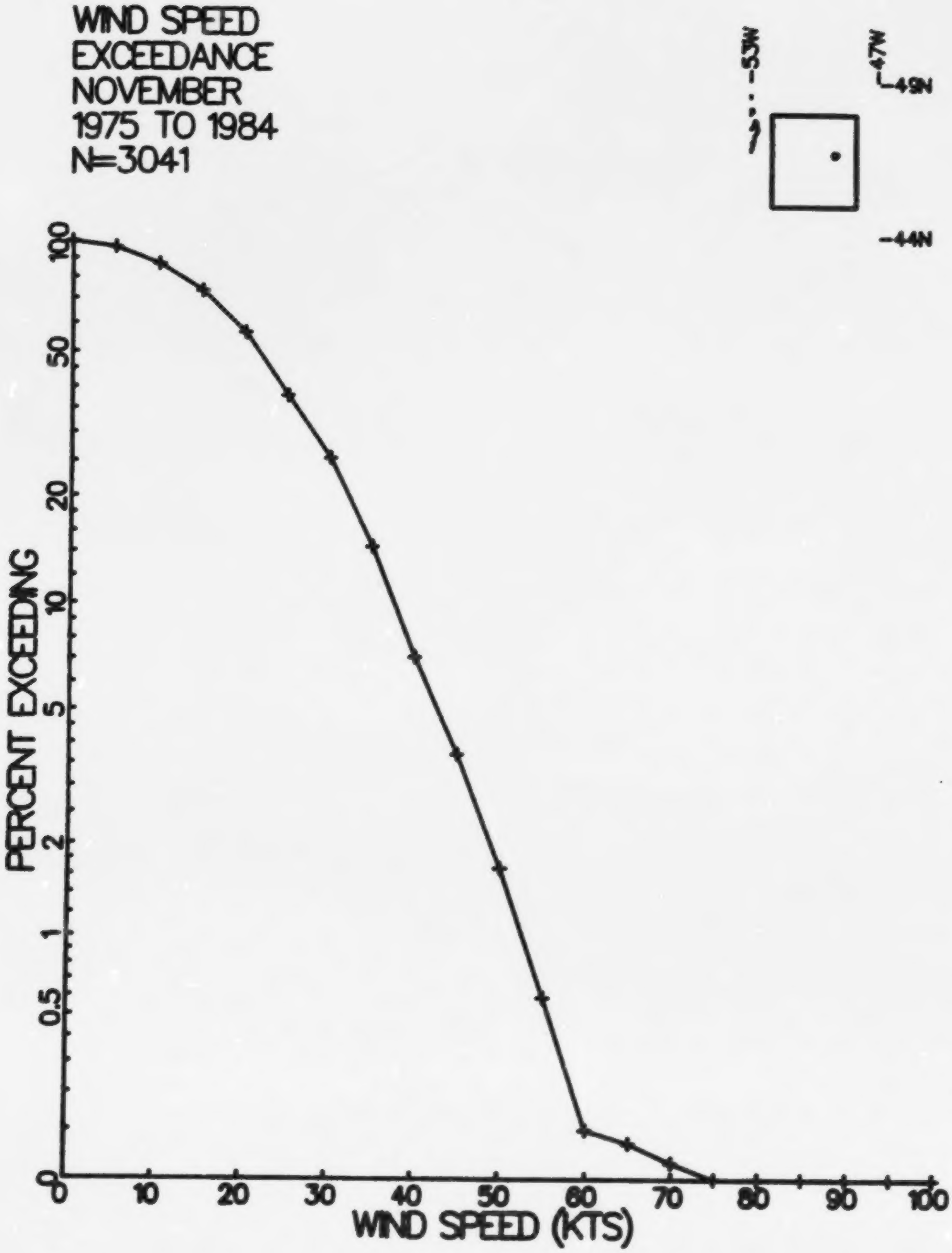


FIGURE 2.17 WIND SPEED EXCEEDANCE, NOVEMBER 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

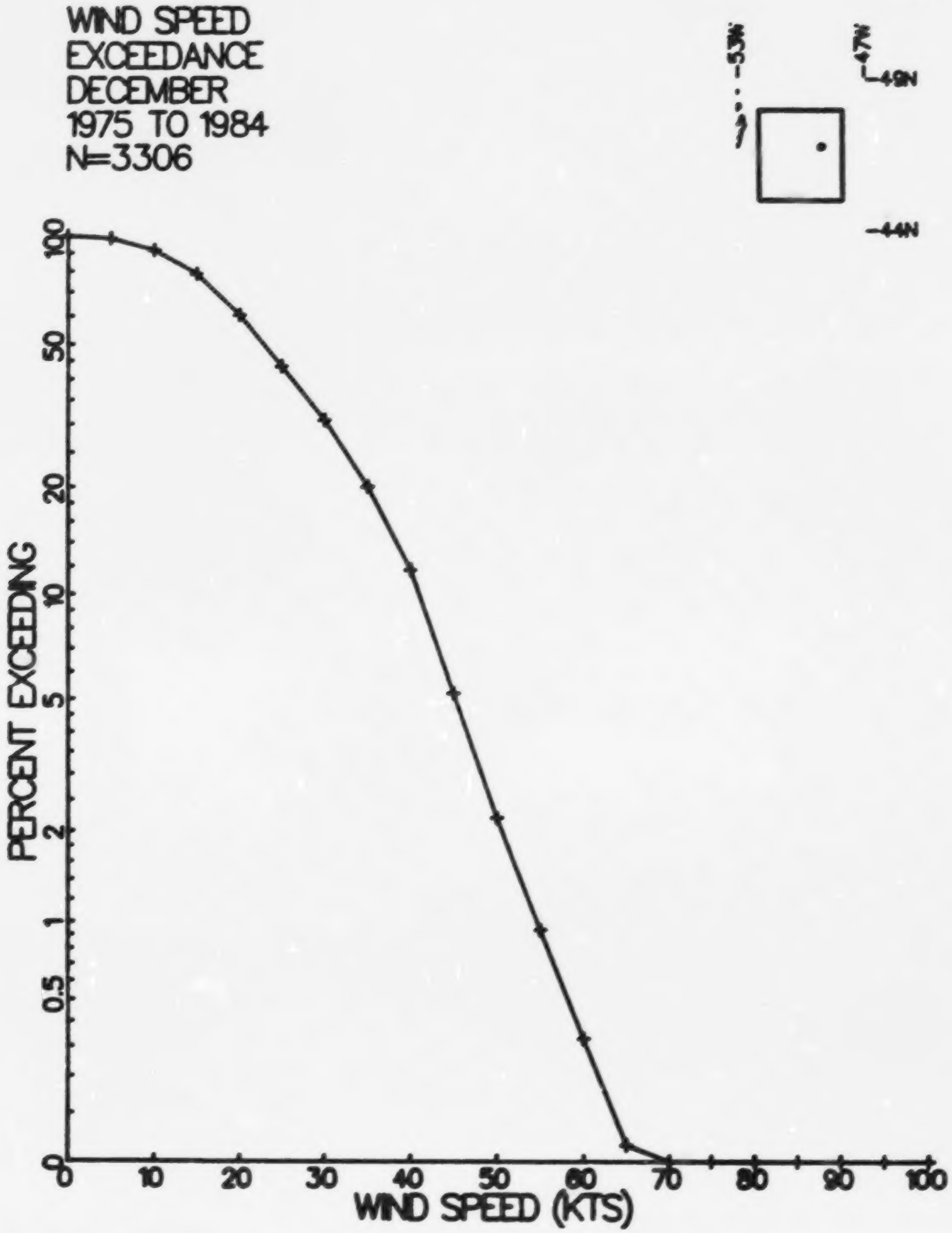


FIGURE 2.18 WIND SPEED EXCEEDANCE, DECEMBER 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

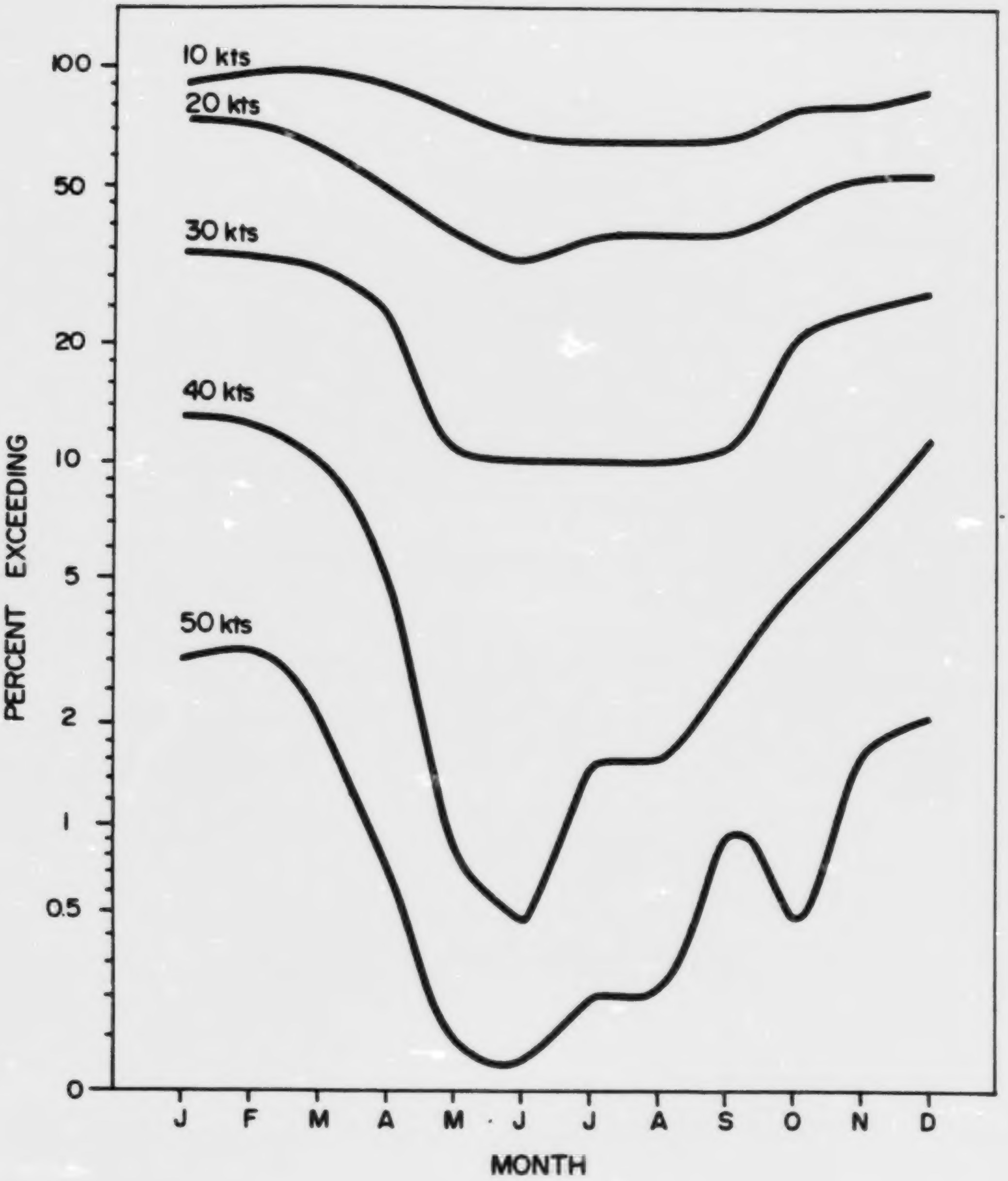


FIGURE 2.19 WIND SPEED EXCEEDANCE BY MONTH, 1975 - 1984

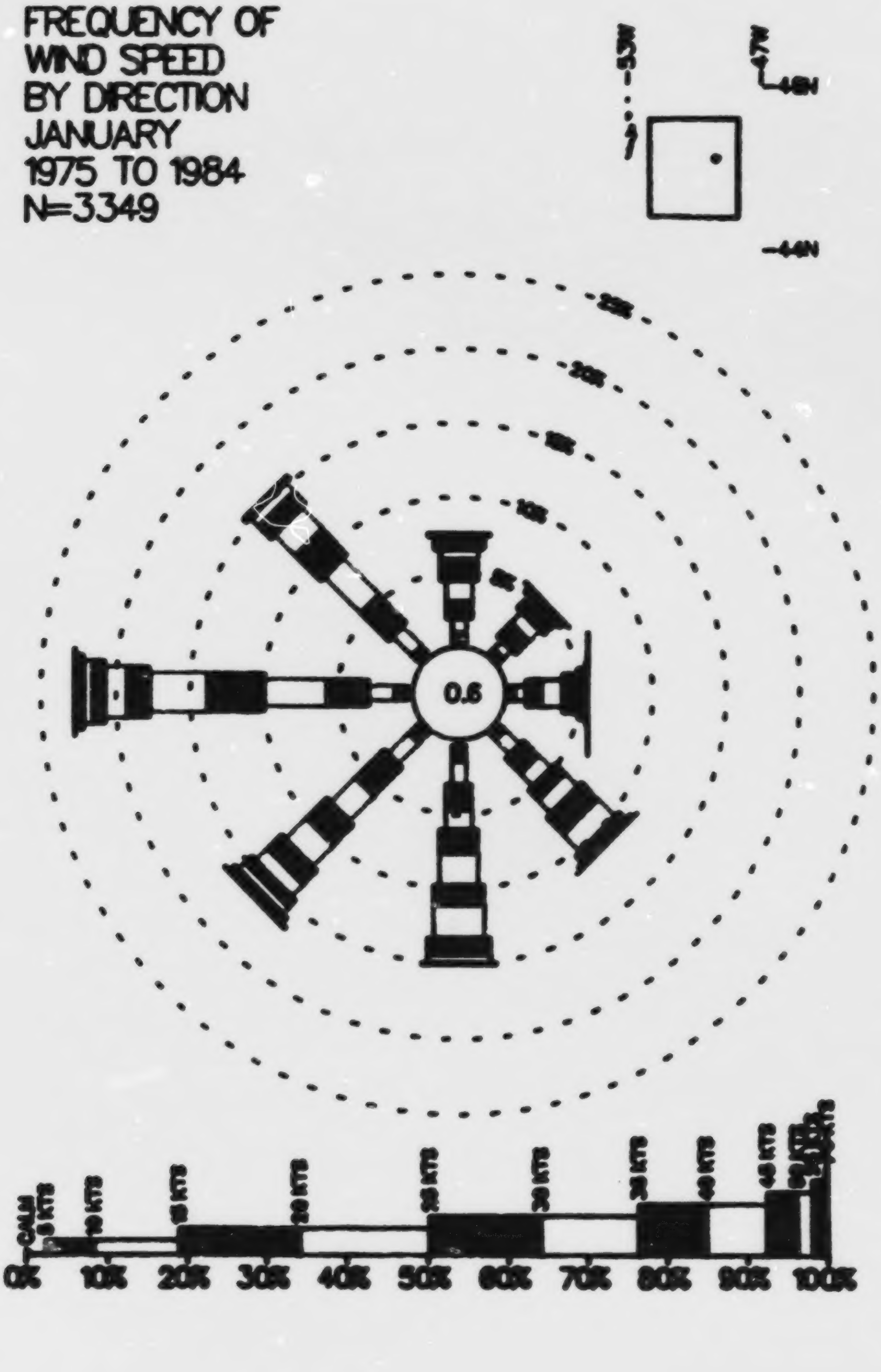


FIGURE 2.20 FREQUENCY OF WIND SPEED BY DIRECTION, JANUARY 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

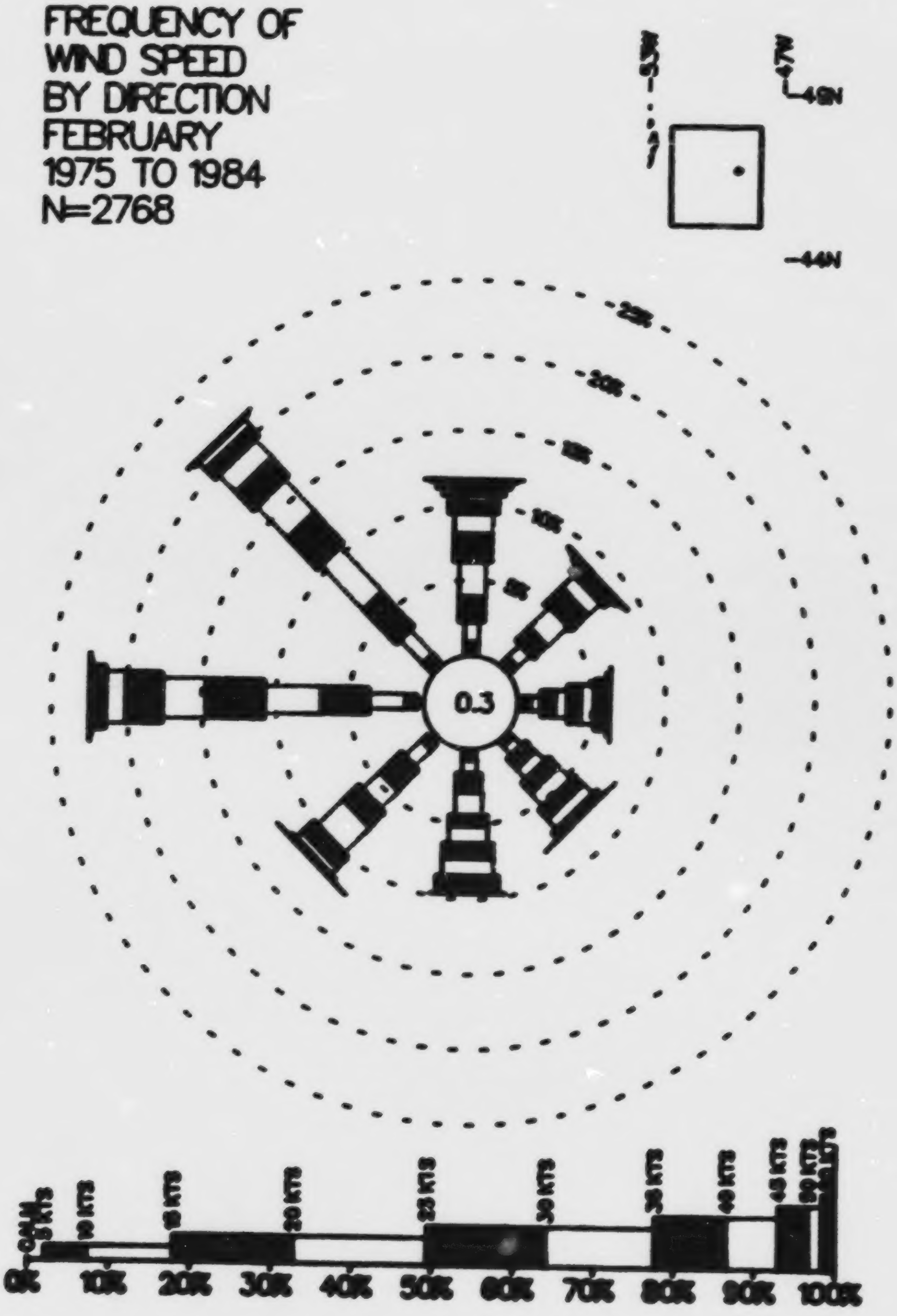


FIGURE 2.21 FREQUENCY OF WIND SPEED BY DIRECTION, FEBRUARY 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

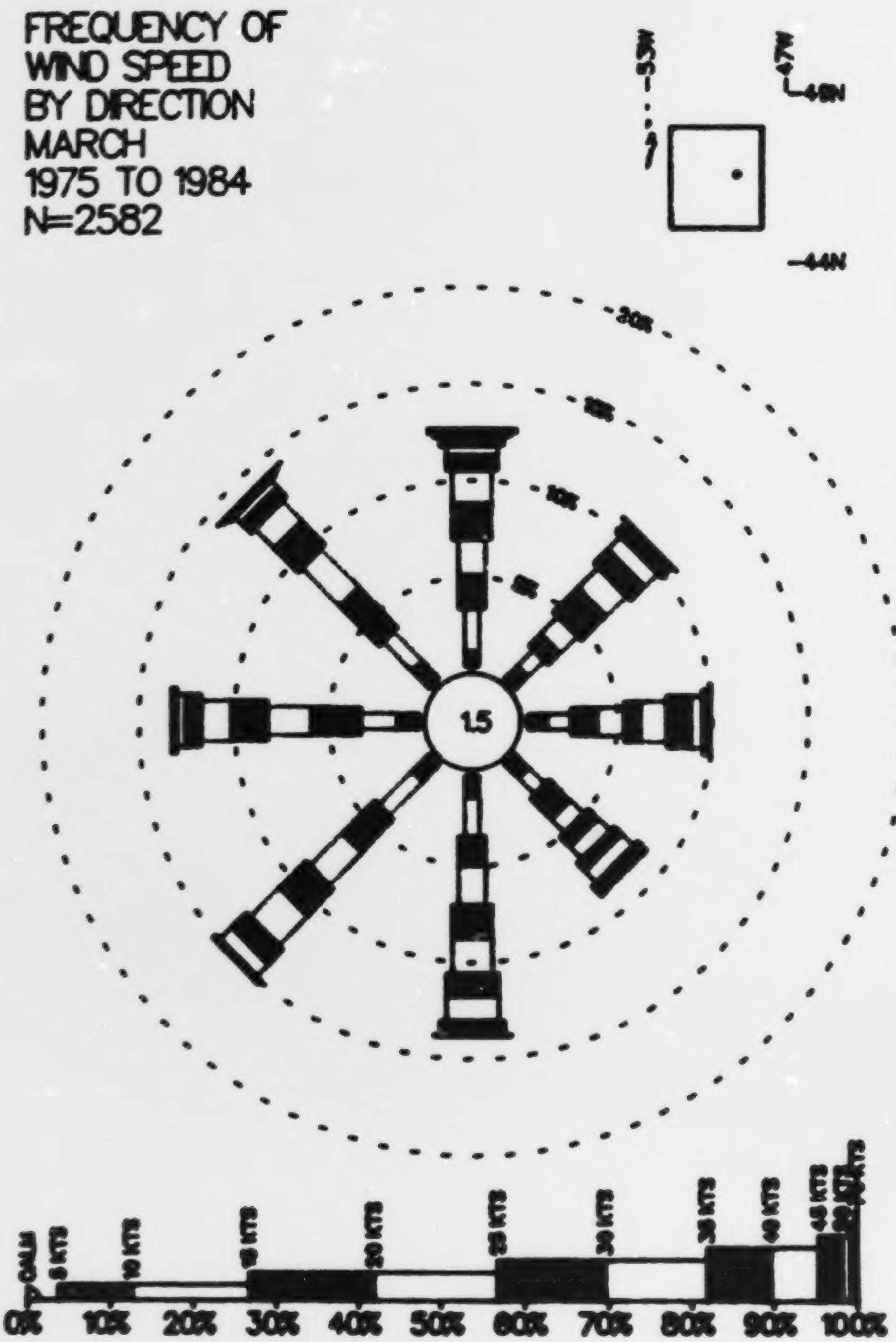


FIGURE 2.22 FREQUENCY OF WIND SPEED BY DIRECTION, MARCH 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

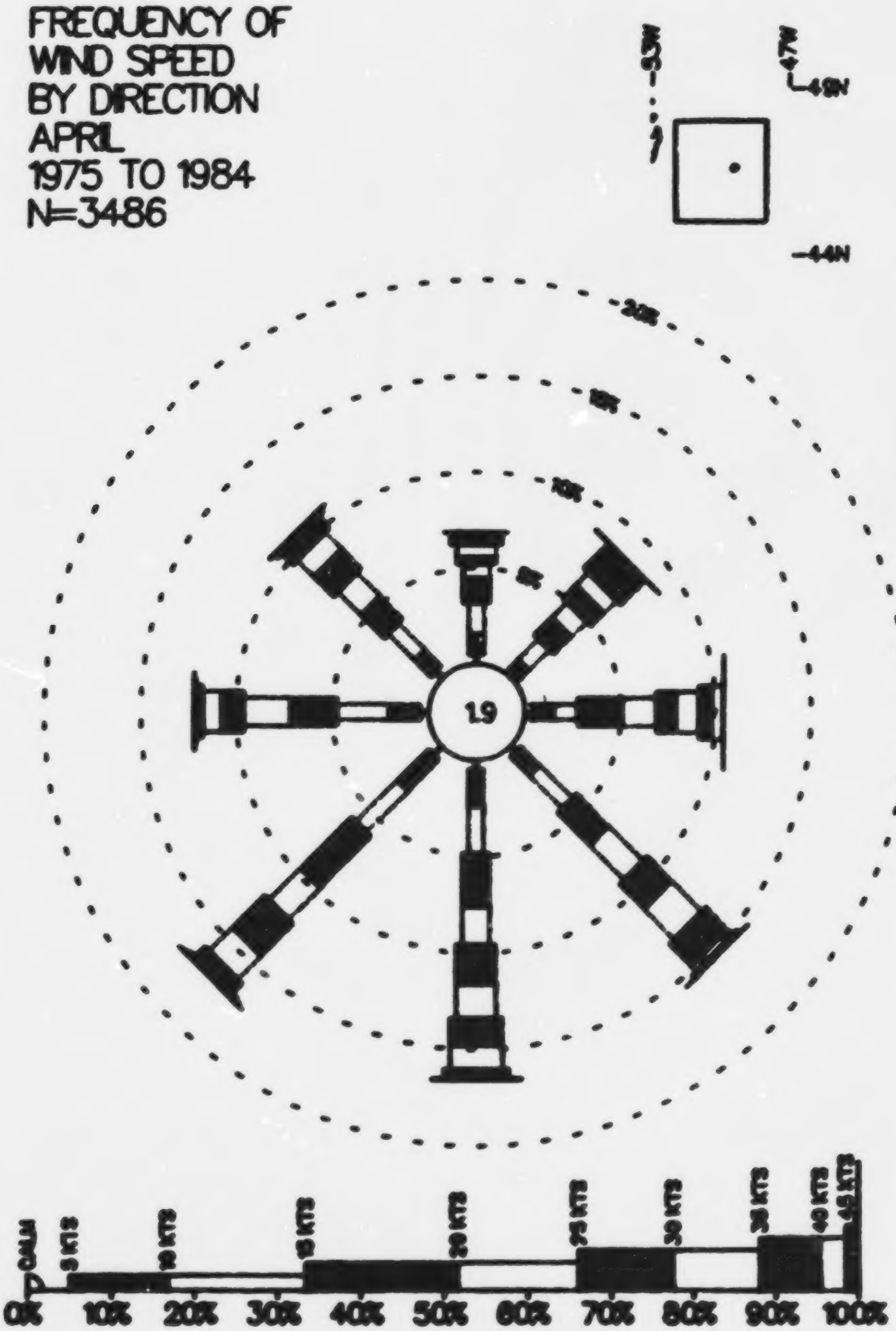


FIGURE 2.23 FREQUENCY OF WIND SPEED BY DIRECTION, APRIL 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

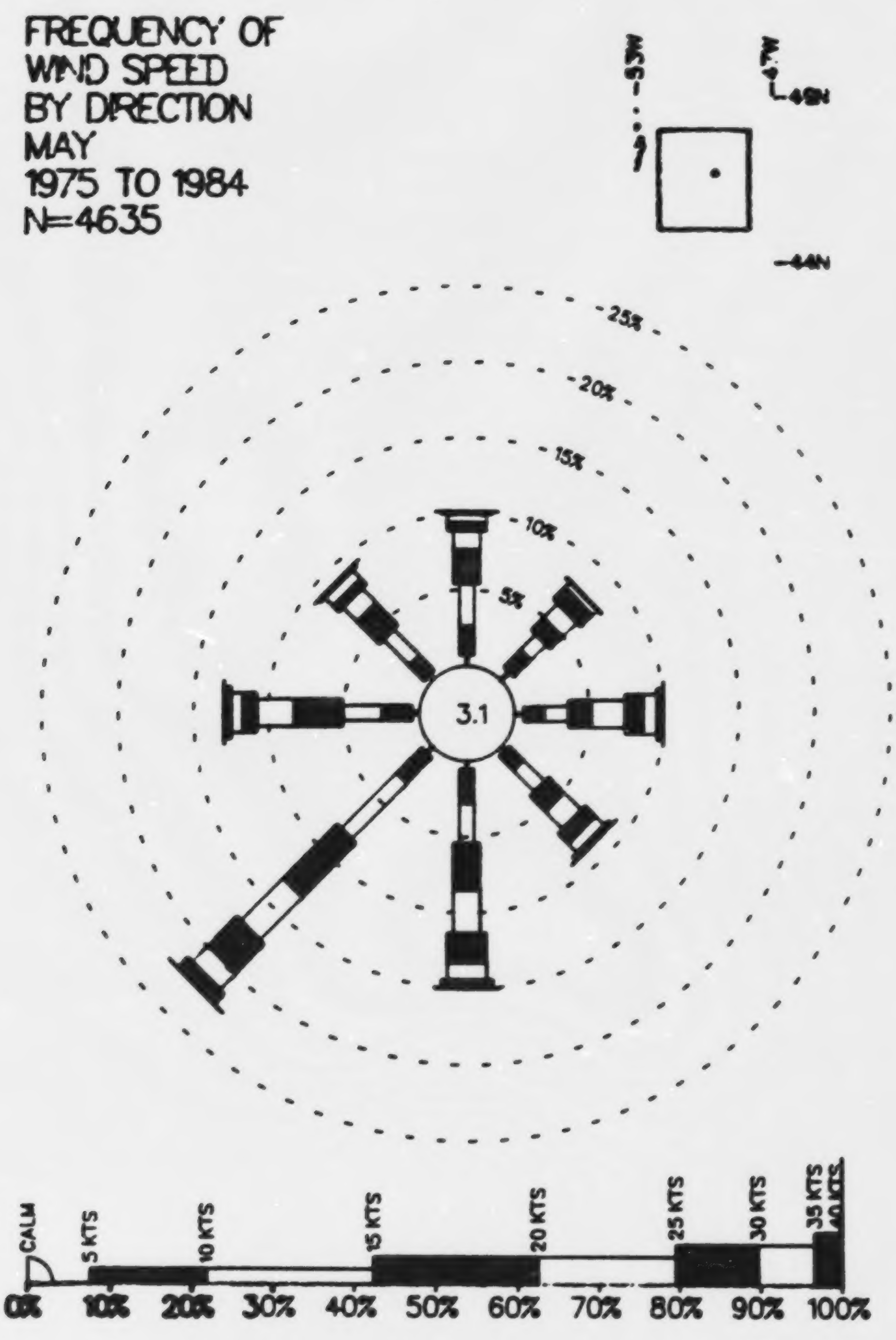


FIGURE 2.24 FREQUENCY OF WIND SPEED BY DIRECTION, MAY 1975 TO 1984
(CANADIAN CLIMATE CENTRE)

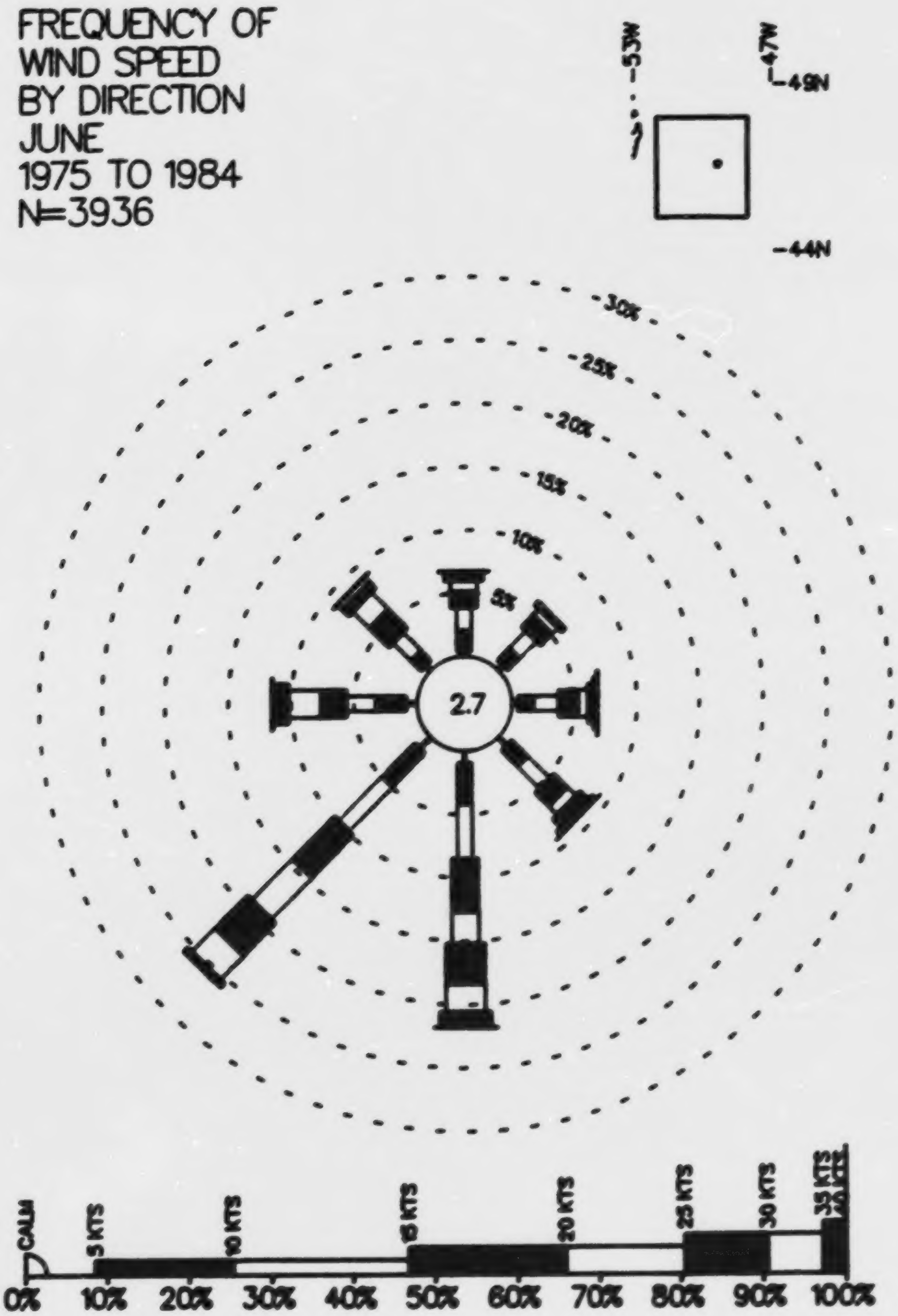


FIGURE 2.25 FREQUENCY OF WIND SPEED BY DIRECTION, JUNE 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

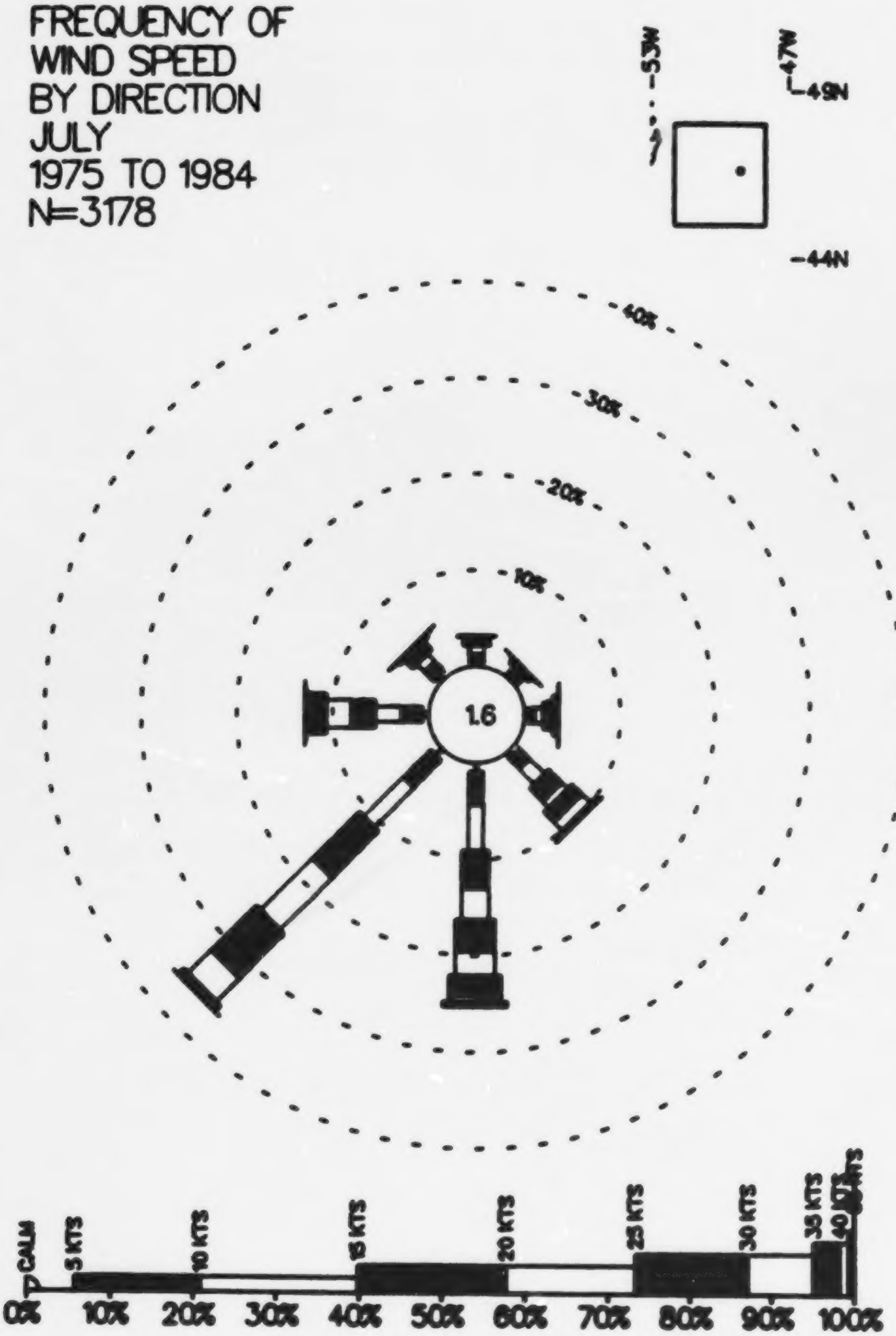


FIGURE 2.26 FREQUENCY OF WIND SPEED BY DIRECTION, JULY 1975 TO 1984 (CANADIAN CLIMATE CENTRE)

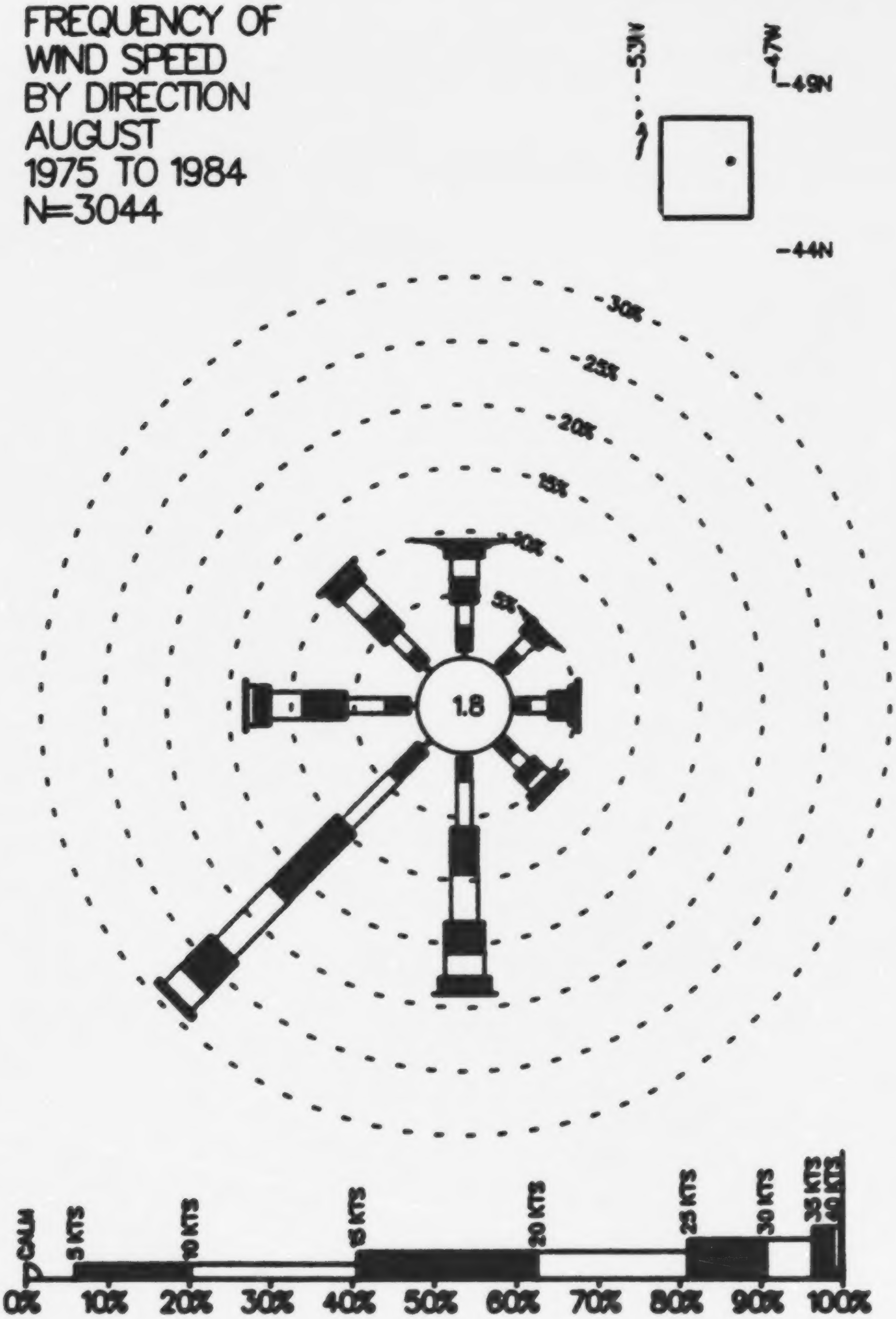


FIGURE 2.27 FREQUENCY OF WIND SPEED BY DIRECTION, AUGUST 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

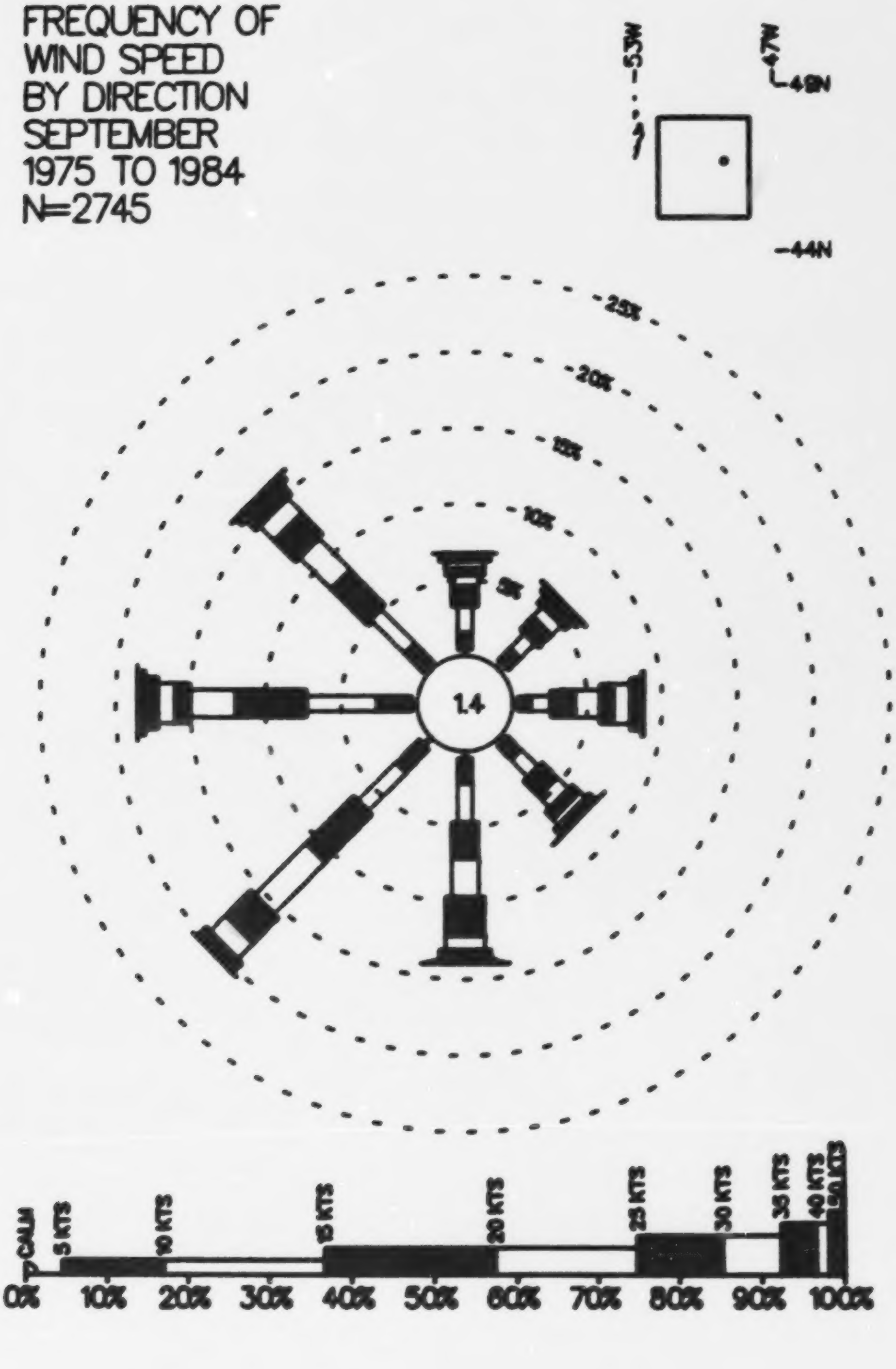


FIGURE 2.28 FREQUENCY OF WIND SPEED BY DIRECTION, SEPTEMBER 1975 TO 1984 (CANADIAN CLIMATE CENTRE)

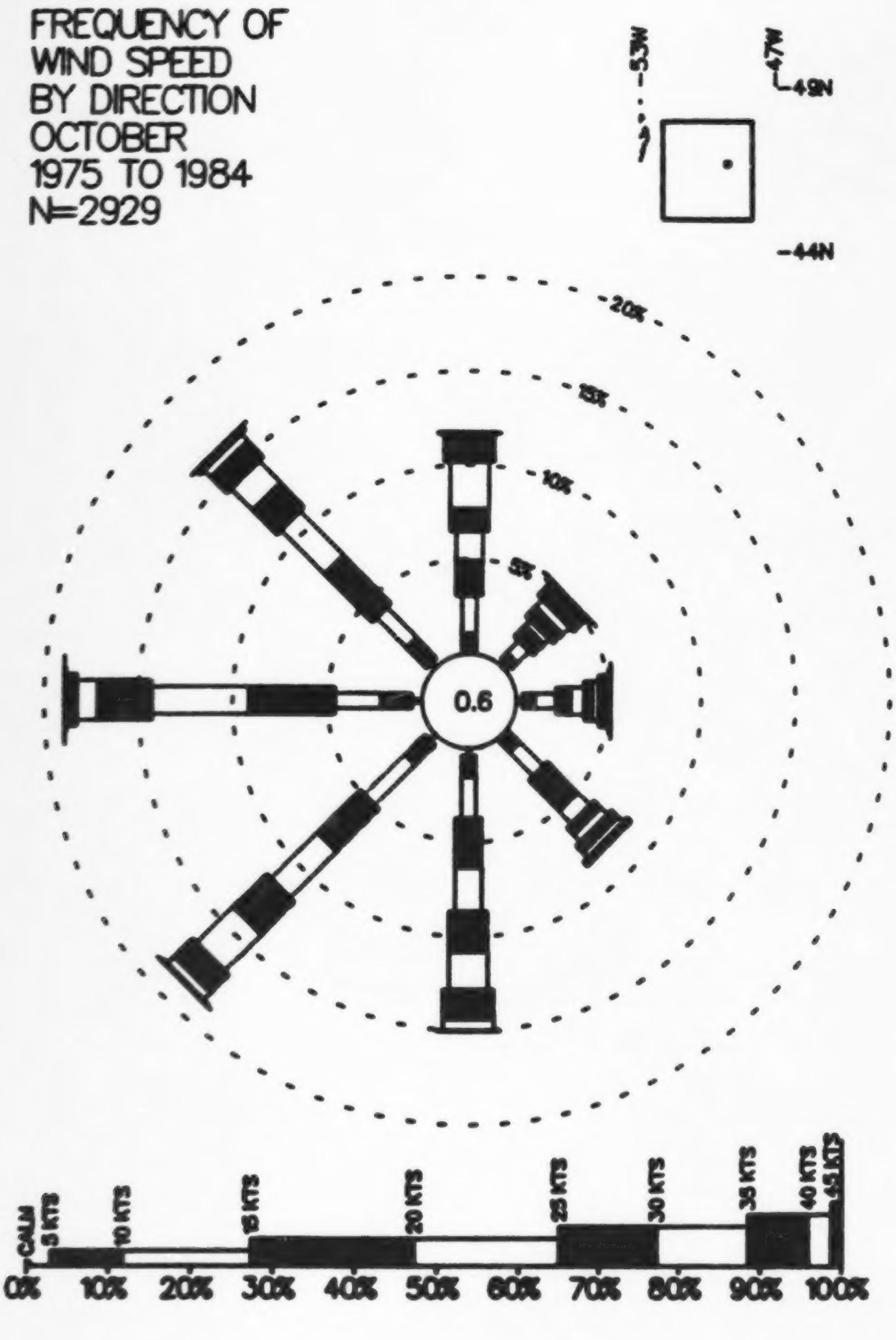


FIGURE 2.29 FREQUENCY OF WIND SPEED BY DIRECTION, OCTOBER 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

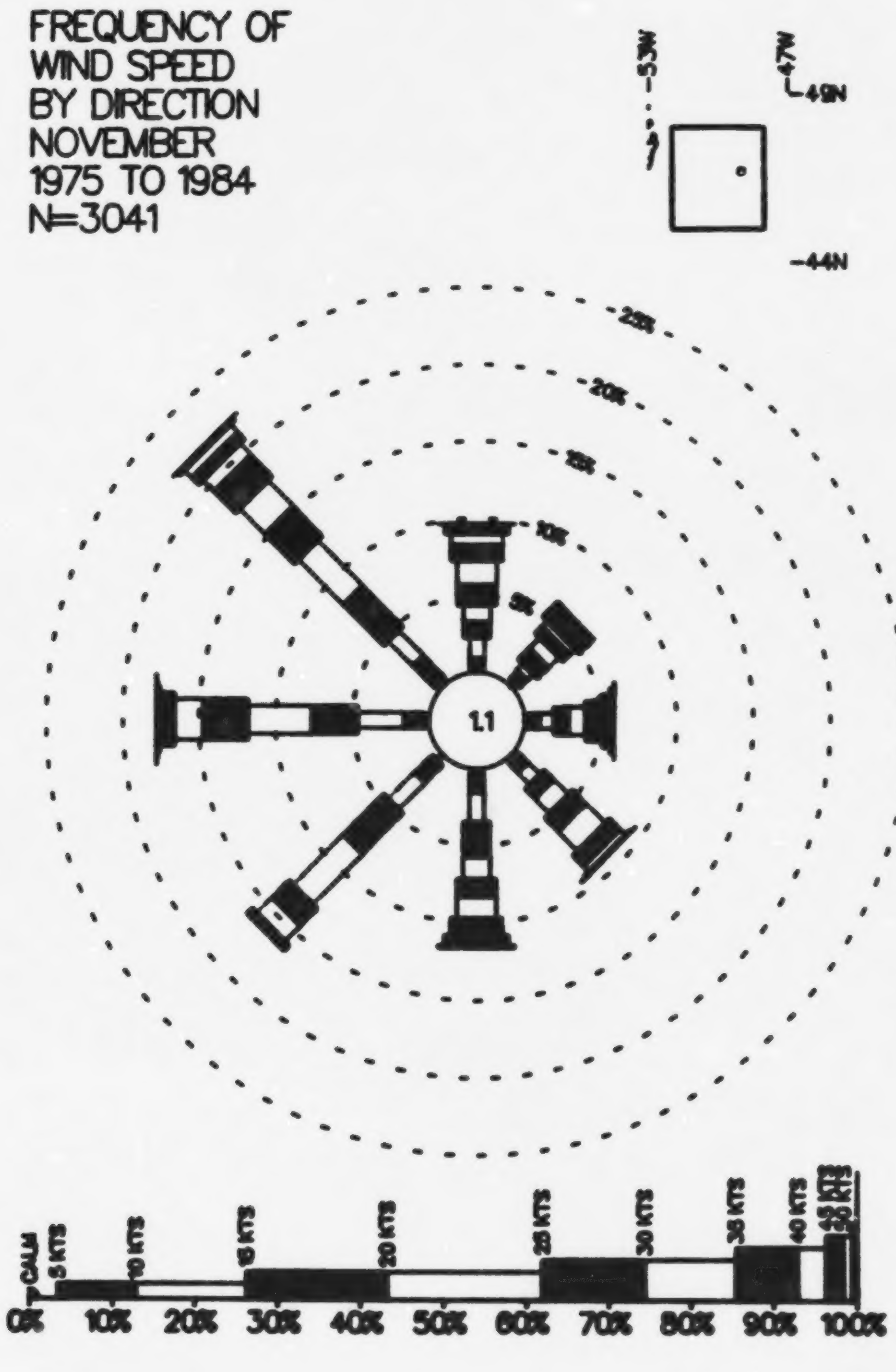


FIGURE 2.30 FREQUENCY OF WIND SPEED BY DIRECTION, NOVEMBER 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

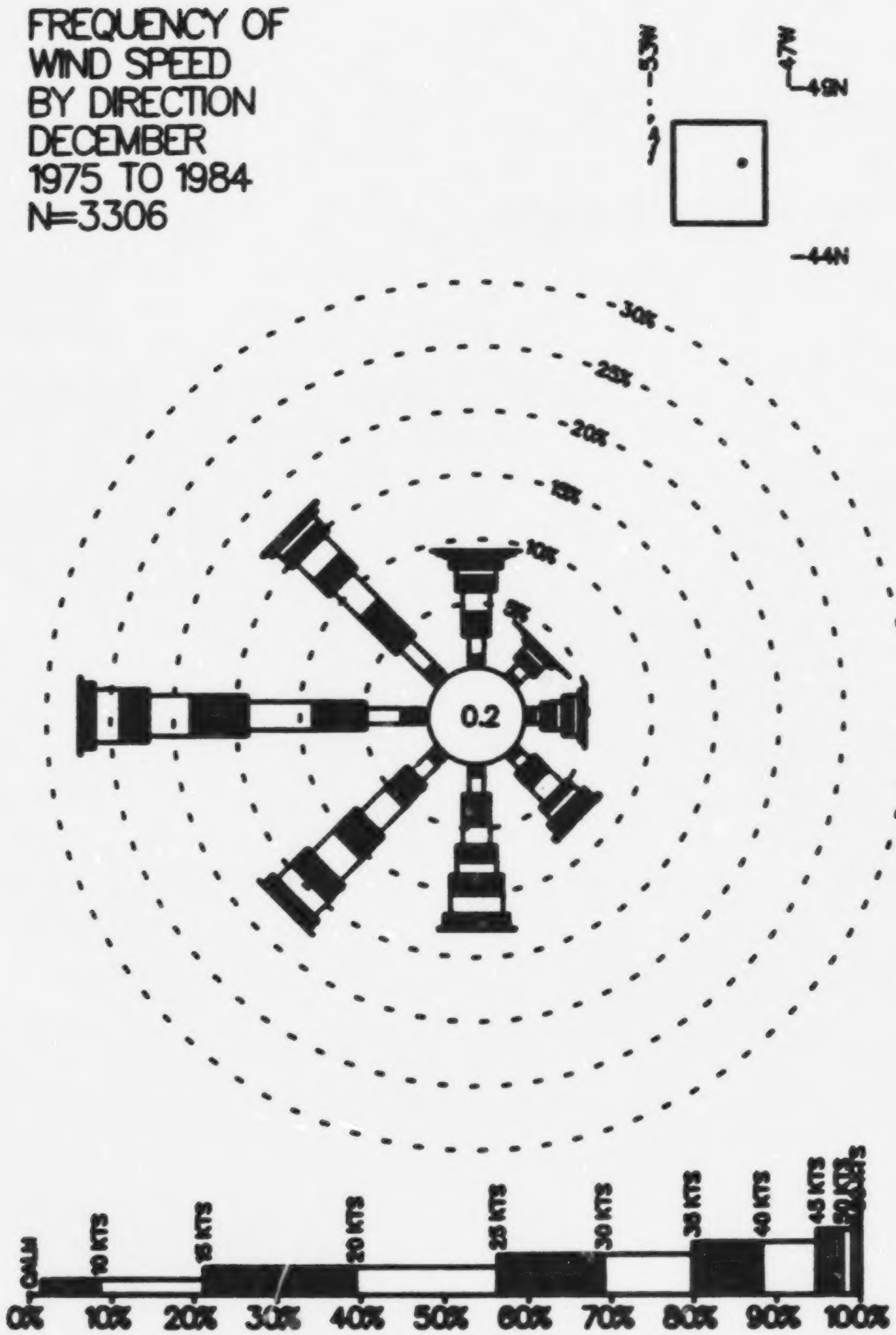


FIGURE 2.31 FREQUENCY OF WIND SPEED BY DIRECTION, DECEMBER 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

TABLE 2.7

SURFACE WINDS, TO DECEMBER 1974

(U.S. Naval Synoptic Observations)

PARAMETER	UNITS	MONTH											
		JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Wind Speed	% ≤ 10 kts	15	10	22	30	42	40	52	51	40	40	30	22
	% ≥ 34 Kts	14	22	9	5	4	3	1	2	4	5	9	9
	Avg. (kts)	19	18.2	17.3	15.4	12.6	11.5	10.1	10.5	12.7	14.6	16.4	17.3
Wind Speed (Percent)	0 - 5 kts	3	3	3	5	9	11	14	12	8	5	4	3
	5 - 7 kts	7	6	8	11	16	17	20	18	13	13	10	8
	8 - 11 kts	14	17	17	19	24	26	28	29	26	24	18	18
	12 - 17 kts	22	22	24	24	26	24	23	25	26	24	24	23
	18 - 22 kts	20	20	18	19	13	13	11	11	14	15	18	19
	23 - 28 kts	15	14	14	12	8	5	4	4	7	10	13	14
	29 - 34 kts	10	10	9	6	4	3	1	1	3	5	8	9
	35 - 41 kts	6	5	4	3	1	1	-	-	1	3	4	4
	42 - 48 kts	3	1	1	1	-	-	-	-	-	1	1	1
	48+ kts	1	1	1	-	-	-	-	-	-	1	-	1
Wind Direction (Percent)	N	14	14	15	12	12	9	8	10	13	15	15	14
	NE	6	8	8	8	6	7	7	7	10	10	10	9
	E	5	6	7	7	6	5	5	6	7	8	7	6
	SE	8	9	10	9	9	7	8	6	8	9	9	8
	S	13	15	12	15	17	19	23	9	17	14	17	15
	SW	12	8	9	13	17	22	23	20	16	12	12	10
	W	18	15	18	18	17	15	12	22	13	13	13	15
	NW	23	24	19	16	13	10	8	15	13	17	15	22
	Calm	1	1	2	2	3	5	6	3	3	2	1	1
Resultant Wind Vector	Kts	7.1	5.5	4.8	4.1	3.6	4.2	3.7	3.1	2.5	3.2	3.1	5.1
	Direction	NW	NW	NW	W	SW	SW	SW	SW	W	NW	NW	NW

2.1.3.2 Pertinent Evaluation Data

These data show that the period from November through March would be the best time for testing the influence of wind speed on sensor detectability. Winds exceeding 30 kts can be reasonably expected over, say, a two-week period. This time period would also permit the best opportunity to carry out tests as the winds correlate with periods of maximum wave height. These are the two environmental parameters expected to exert the most influence on sensor detectability.

2.1.4 Currents

2.1.4.1 Historical Data

Figure 2.32 shows the generalized mean current speeds for the east coast of Canada. In the Grand Banks region, the current is predominantly a cold current from the north, called the Labrador Current, which moves at approximately 7 to 8 kts per day. Its direction and speed are affected by seasonal meteorologic shifts, land configuration and bathymetry. On the Grand Banks, the temperature of the current is generally 0 to 4°C, with a salinity of approximately 33 to 34.9%. Off the Grand Banks, where mixing with the Gulfstream occurs to form the North Atlantic Drift, the temperature ranges from 4 to 14°C, and salinity from 35 to 35.8%. At the front where the Gulf Stream and Labrador Currents meet, a series of interactions occur, forming eddy currents and upwellings. Eddies form throughout the year, especially in the study area. They are generally 80 to 120 km in diameter and last 1 to 3 months. Anticyclonic eddies tend to be faster (33.4 cm sec^{-1}) than cyclonic eddies (24.7 cm sec^{-1}). Current meandering also occurs in the interaction zone, with wavelengths between 175 and 375 km, amplitudes of 50 to 100 km, and speeds varying from 25 to 40 cm sec^{-1}.

2.1.4.2 Pertinent Evaluation Data

Currently, other than the local current, speed should have no significant bearing on small object detection. The only areas in which currents would have some importance are in their general effect on sensing backgrounds, and their effect on drift in search areas.

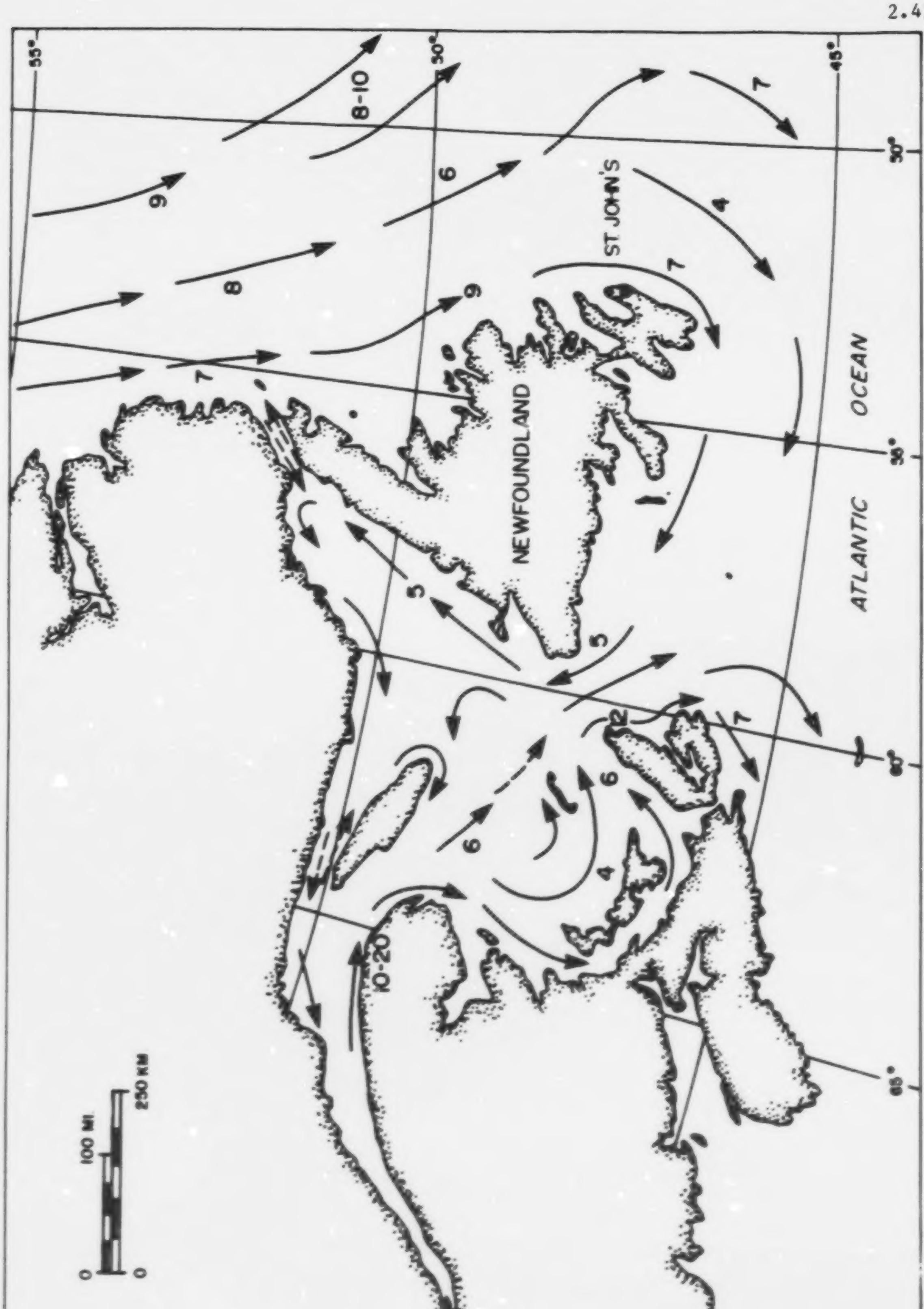

NEWFOUNDLAND
ST. JOHN'S
ATLANTIC
OCEAN
9
8-10
8
6
9
7
7
4
7
5
5
12
7
6
6
4
10-20
55°
50°
45°
60°
65°
50°
55°
0
100 MI
0
250 KM

FIGURE 2.32 GENERALIZED MEAN CURRENTS (Speed: Nautical Miles/Day) (Markham WE, 1980, P.56)

2.1.5 Weather

The weather on the Grand Banks is highly variable and usually obscured by some form of precipitation. Weather data are subdivided into air temperature, pressure, precipitation, visibility and operational weather.

2.1.5.1 Air Temperature

(a) Historical Data

The mean temperature range on the Grand Banks is from -1.2°C in February to 14.4°C in August (Table 2.8). The period from January to March has basically sub-zero temperatures. Rapid warming commences in April, peaking in August, and generally decreasing by November. The median and 95% upper and lower limits and extremes for air temperature, dew point temperature and dew point depression for the period from 1975 to 1984 are given in Figures 2.33 to 2.35.

(b) Pertinent Evaluation Data

The above information shows that extreme cold temperatures will occur from January to March, and extreme high temperatures in July to September. The colder temperatures coincide with the cold sea surface temperatures, highest wind speeds and wave heights. Extreme varying conditions will also occur in this time period. The warmer temperatures correspond to the warmest sea surface temperature conditions, lowest wind speeds and wave heights. Thus, two main ocean/climate scenarios can be identified for detection tests.

2.1.5.2 Pressure

(a) Historical Data

Figure 2.36 gives the range of sea level pressure data for the evaluation area. The greatest pressure differentials occur from November through March. This coincides with the extremes for most environmental parameters and with the storm season on the Grand Banks. The data cover the period from 1975 to 1984.

TABLE 2.8

MONTHLY MEAN TEMPERATURES ON THE GRAND BANKS

[Petro-Canada Exploration Inc., 1981]

MONTH	TEMPERATURE (°C)
January	-0.6
February	-1.2
March	-0.3
April	1.3
May	3.2
June	6.8
July	11.5
August	14.4
September	12.7
October	8.8
November	5.3
December	2.0
January	-0.6

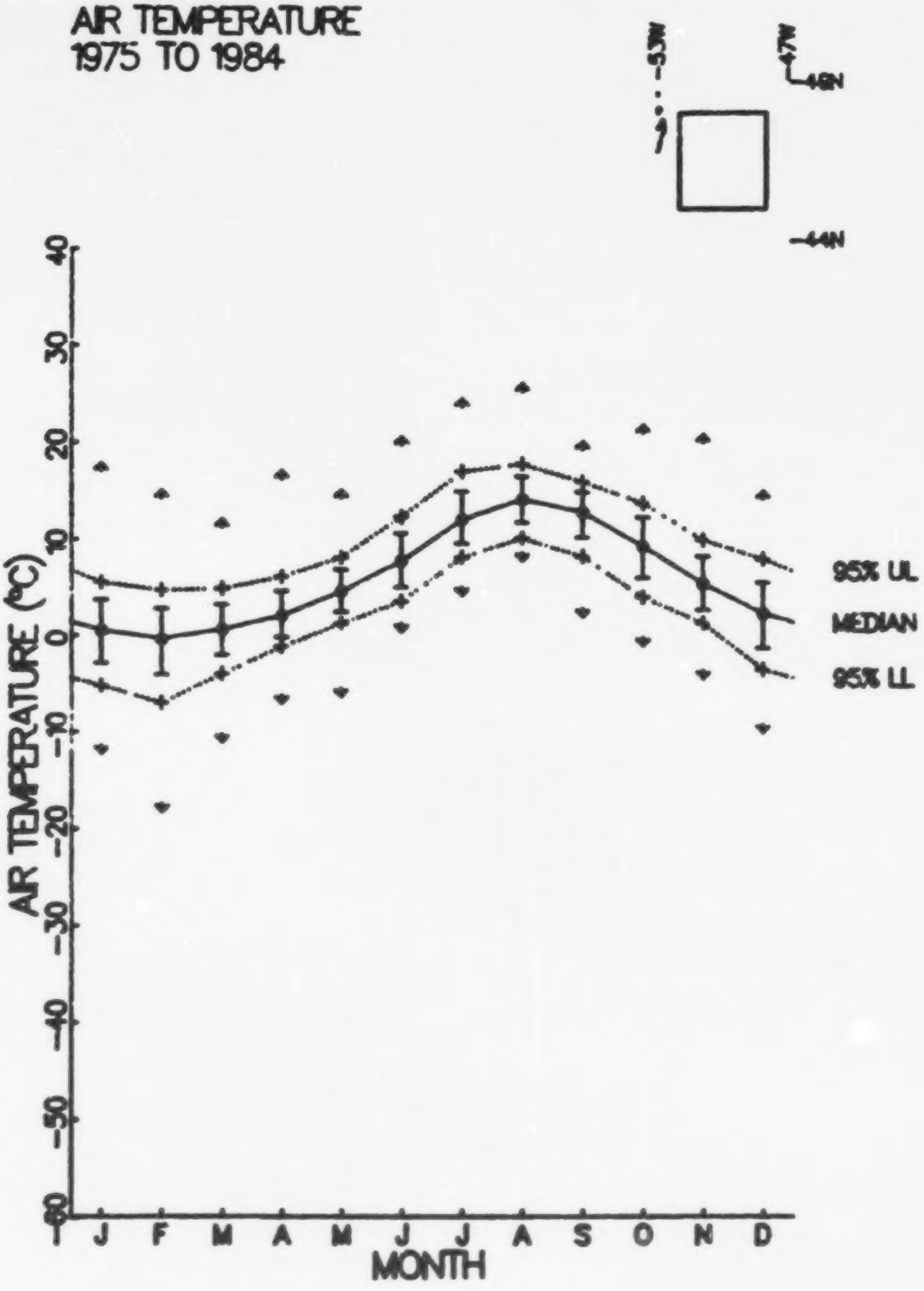


FIGURE 2.33 AIR TEMPERATURE, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

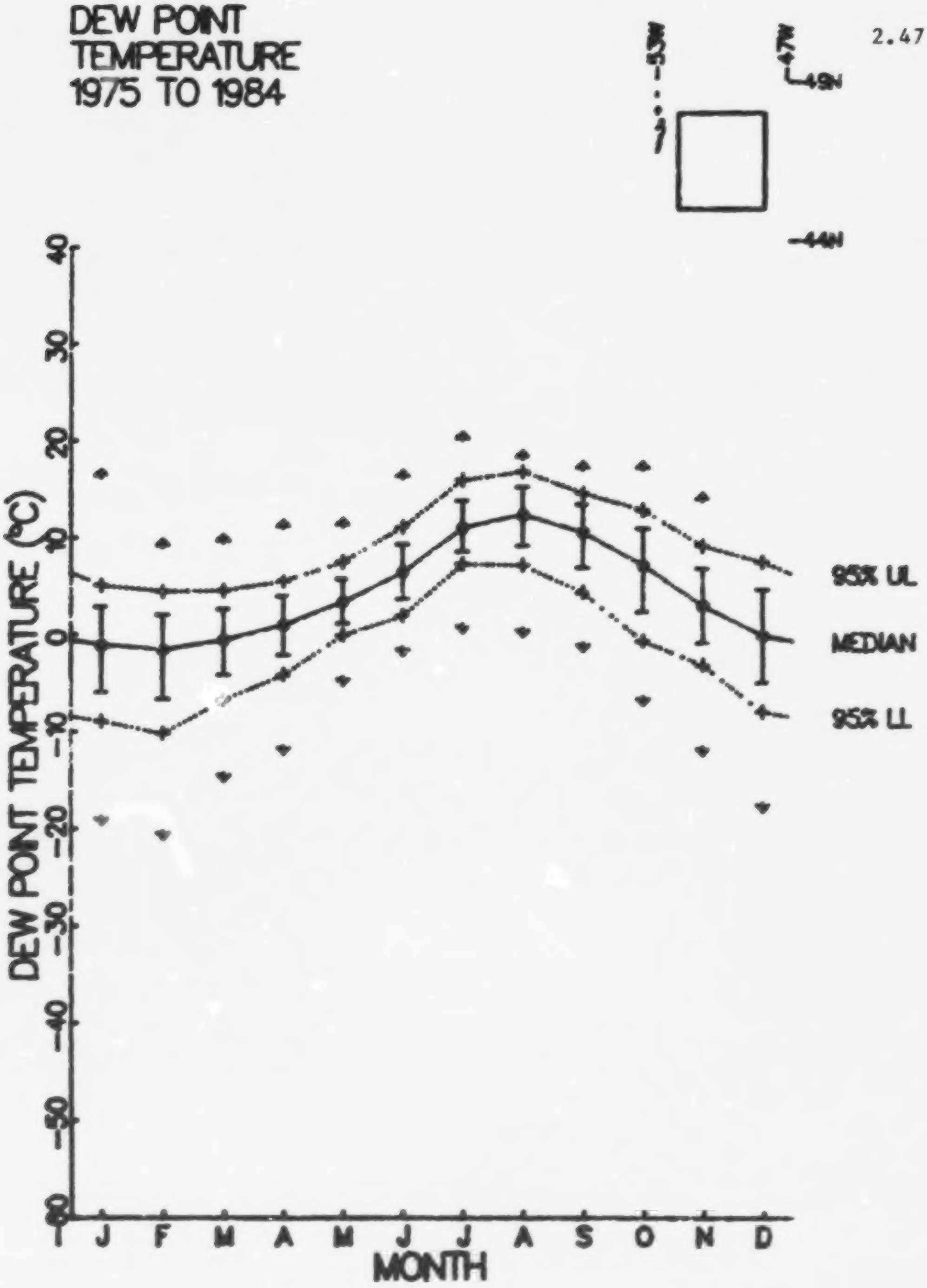


FIGURE 2.34 DEW POINT TEMPERATURE, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

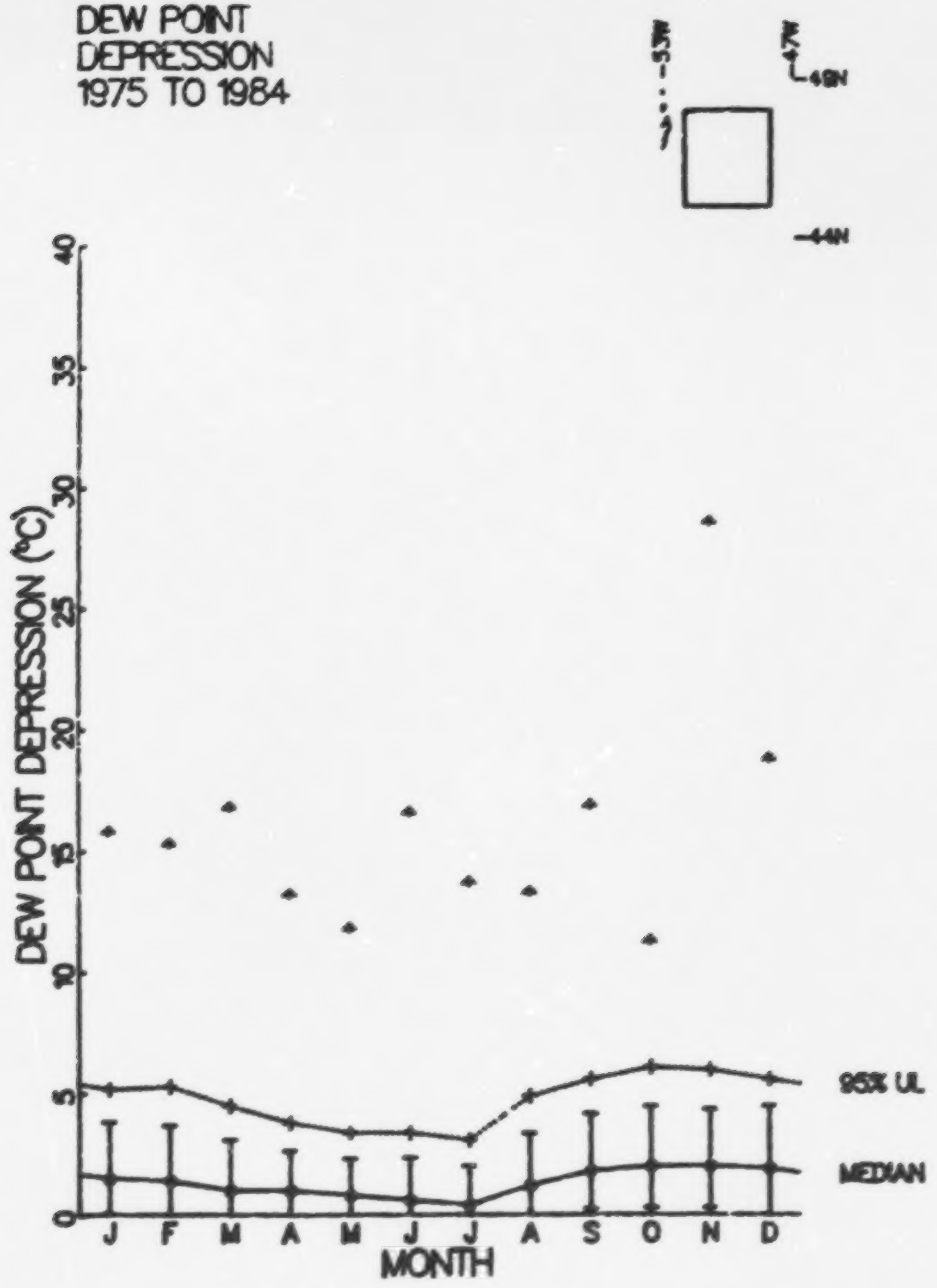


FIGURE 2.35 DEW POINT DEPRESSION, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

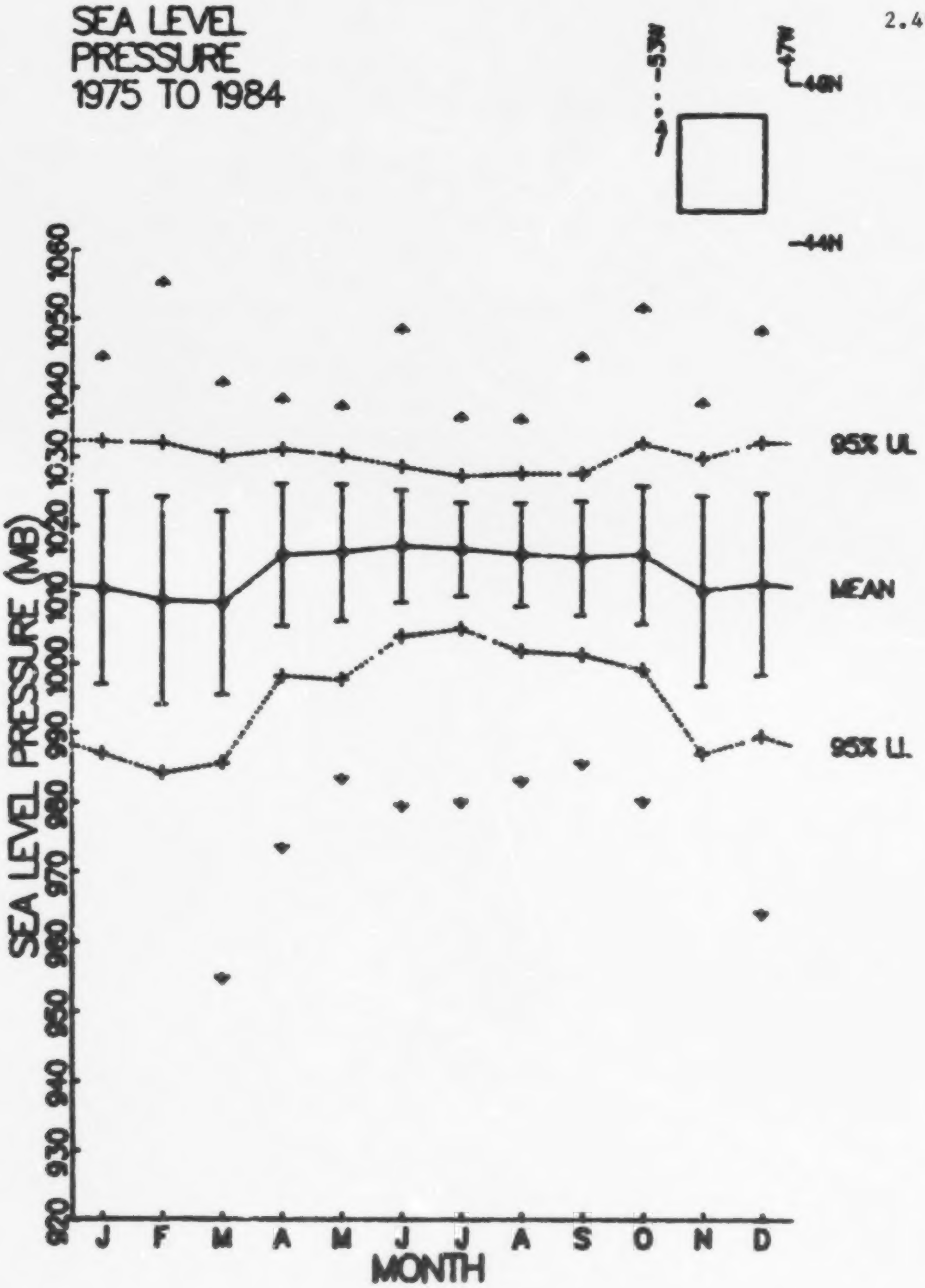


FIGURE 2.36 SEA LEVEL PRESSURE 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

(b) Pertinent Evaluation Data

The most pertinent fact derived from these data is the enormous pressure differentials that occur, particularly in December, January and February. These signify the extreme storm conditions that can exist, such as the 'monster' storms of the type associated with the Ocean Ranger disaster.

2.1.5.3 Moisture/Precipitation

(a) Historical Data

Moisture/precipitation can occur in many forms. The Grand Banks weather is associated with all types from simple humidity to snow and hail. The following types of moisture/precipitation were derived from the Canadian Climate Centre data base covering the period from 1975 to 1984. The data basically serve to illustrate the variety of conditions that can occur:

(i)	Vapour pressure	(Figure 2.37)
(ii)	Humidity	(Figure 2.38)
(iii)	Precipitation	(Figure 2.39)
(iv)	Freezing precipitation	(Figure 2.40)
(v)	Rime	(Figure 2.41)
(vi)	Hail	(Figure 2.42)
(vii)	Thunder	(Figure 2.43)

(b) Pertinent Evaluation Data

In terms of conditions that can exist for evaluating sensors, the most important data derived from this data are the high levels of humidity, which will affect visual and infrared detection methods; the high precipitation levels, both rain and snow, which occur from December to March and will have potential effect on all detection systems; the potential for freezing precipitation, especially from January to March, which will alter the means of detecting the target; and the presence of rime or frost, particularly during February and the beginning of April. Figure 2.42 shows that hail may also be a problem at certain times.

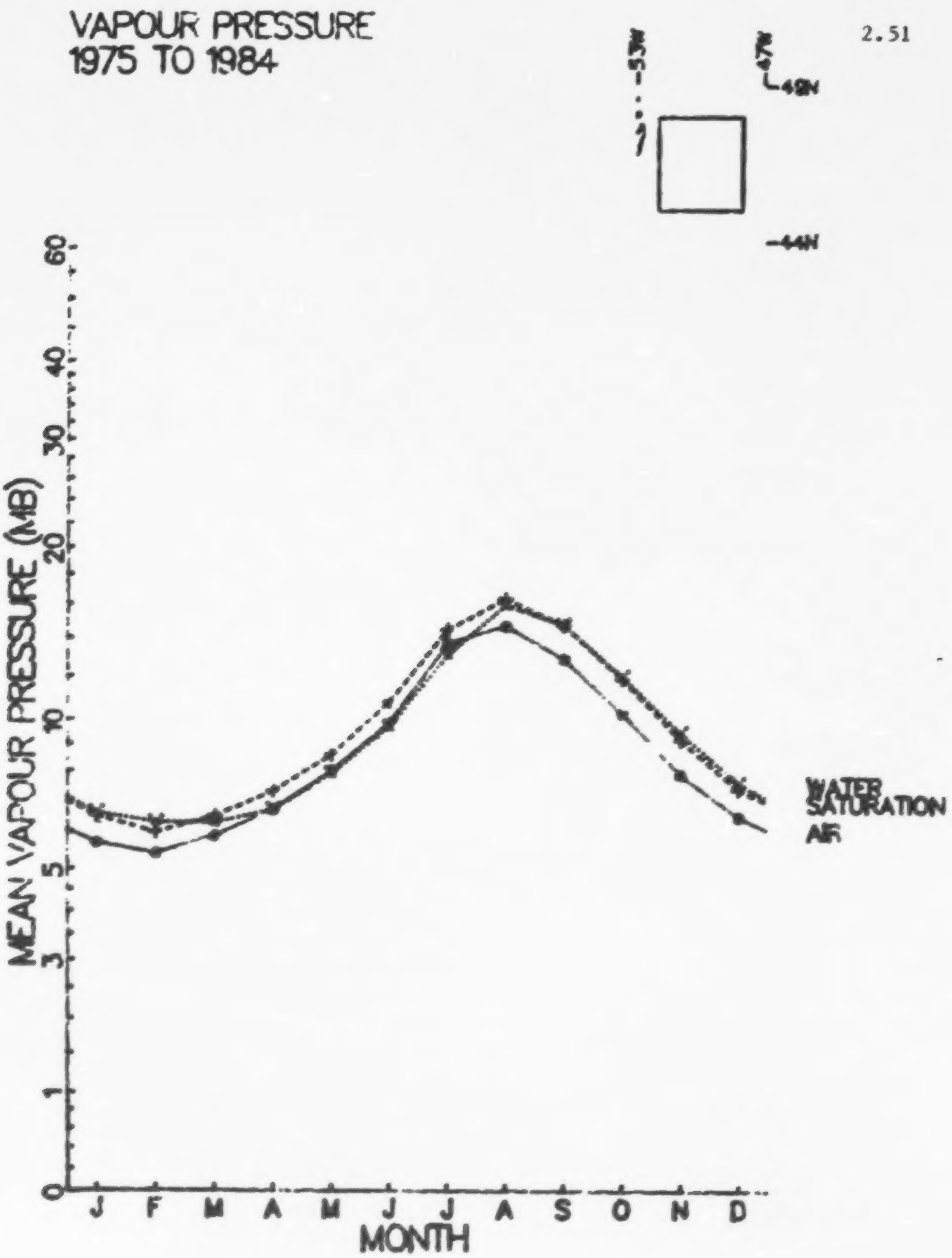


FIGURE 2.37 VAPOUR PRESSURE, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

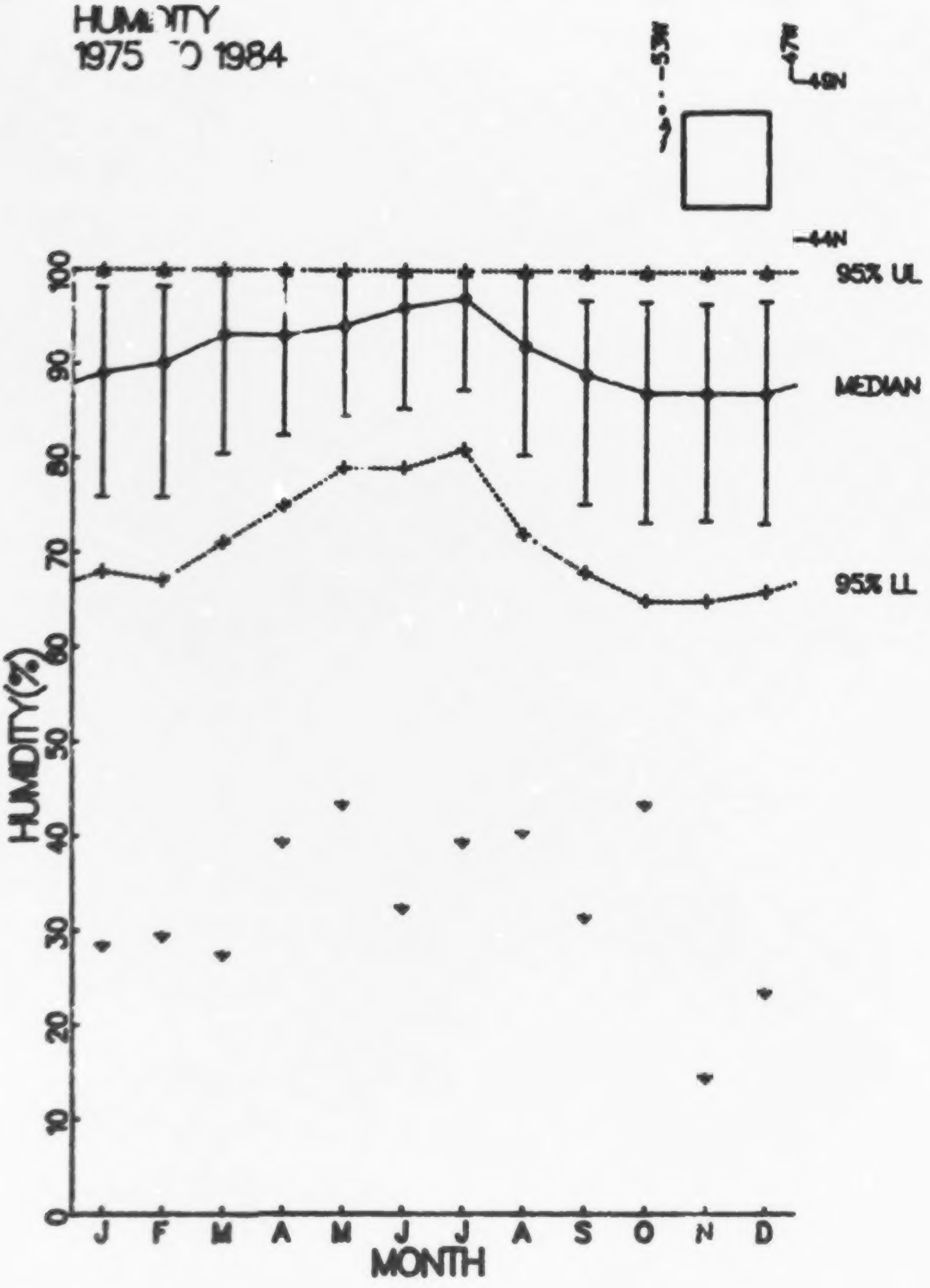


FIGURE 2.38 HUMIDITY, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

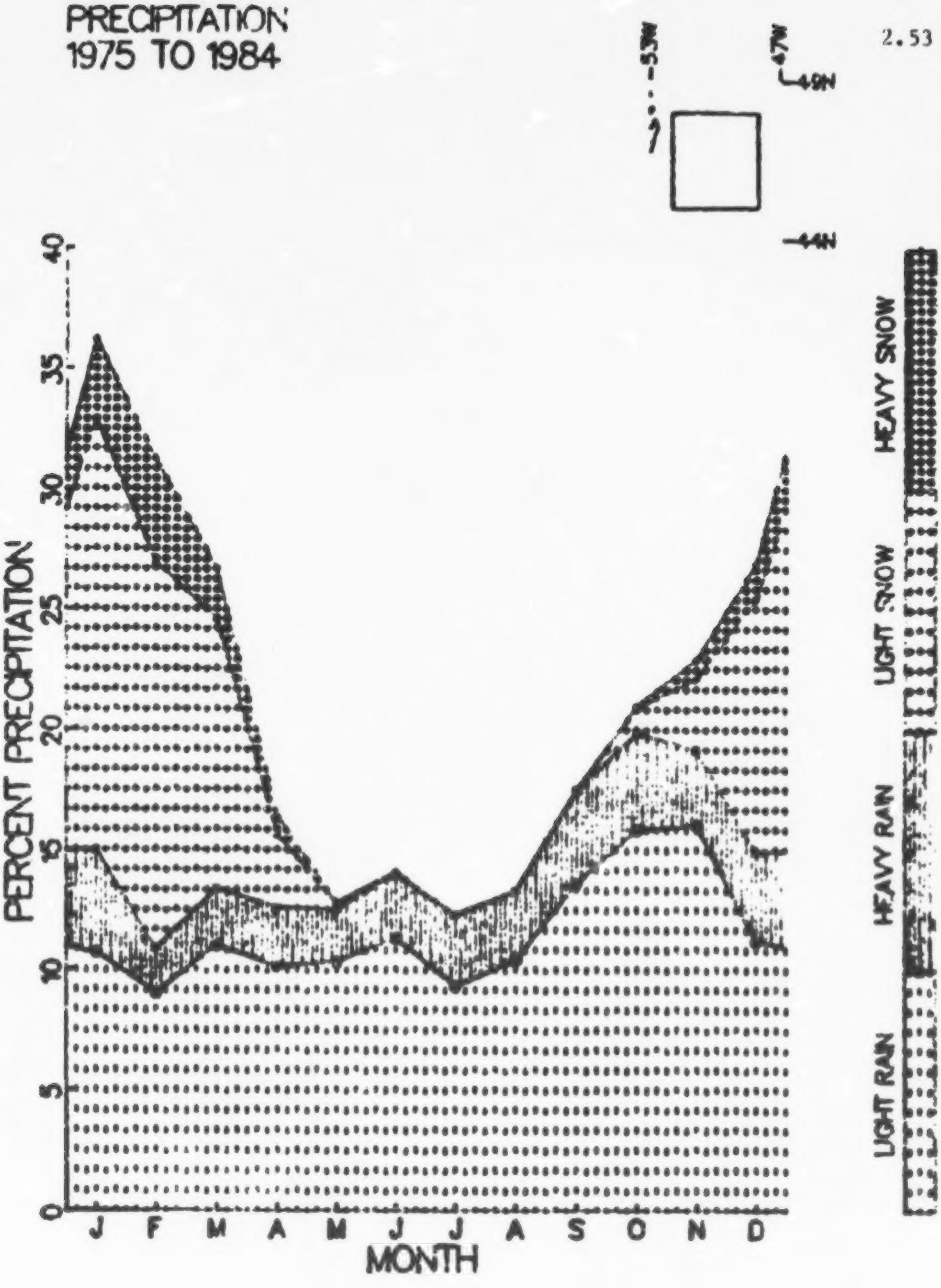


FIGURE 2.39 PRECIPITATION, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

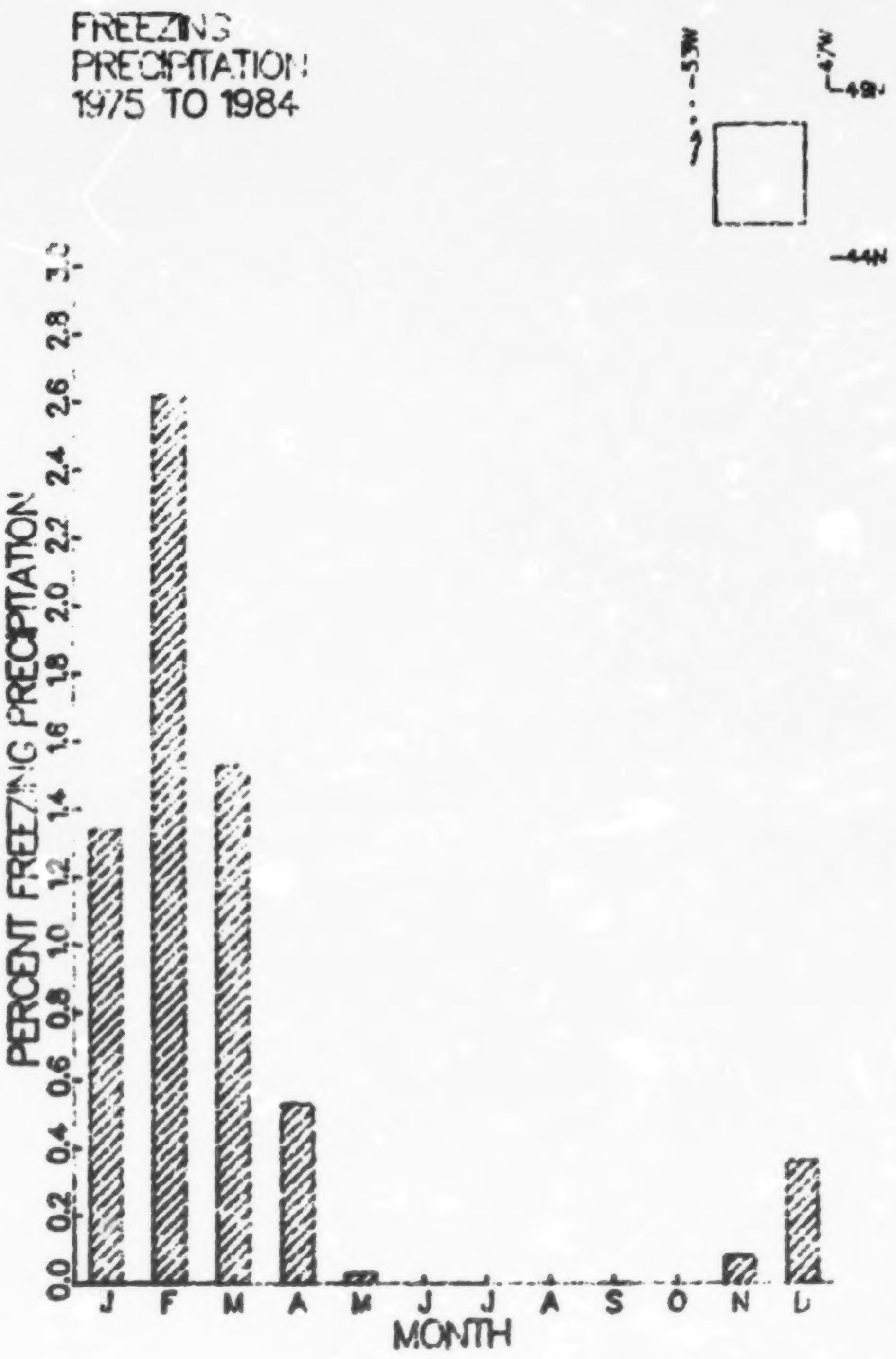


FIGURE 2.40 FREEZING PRECIPITATION, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

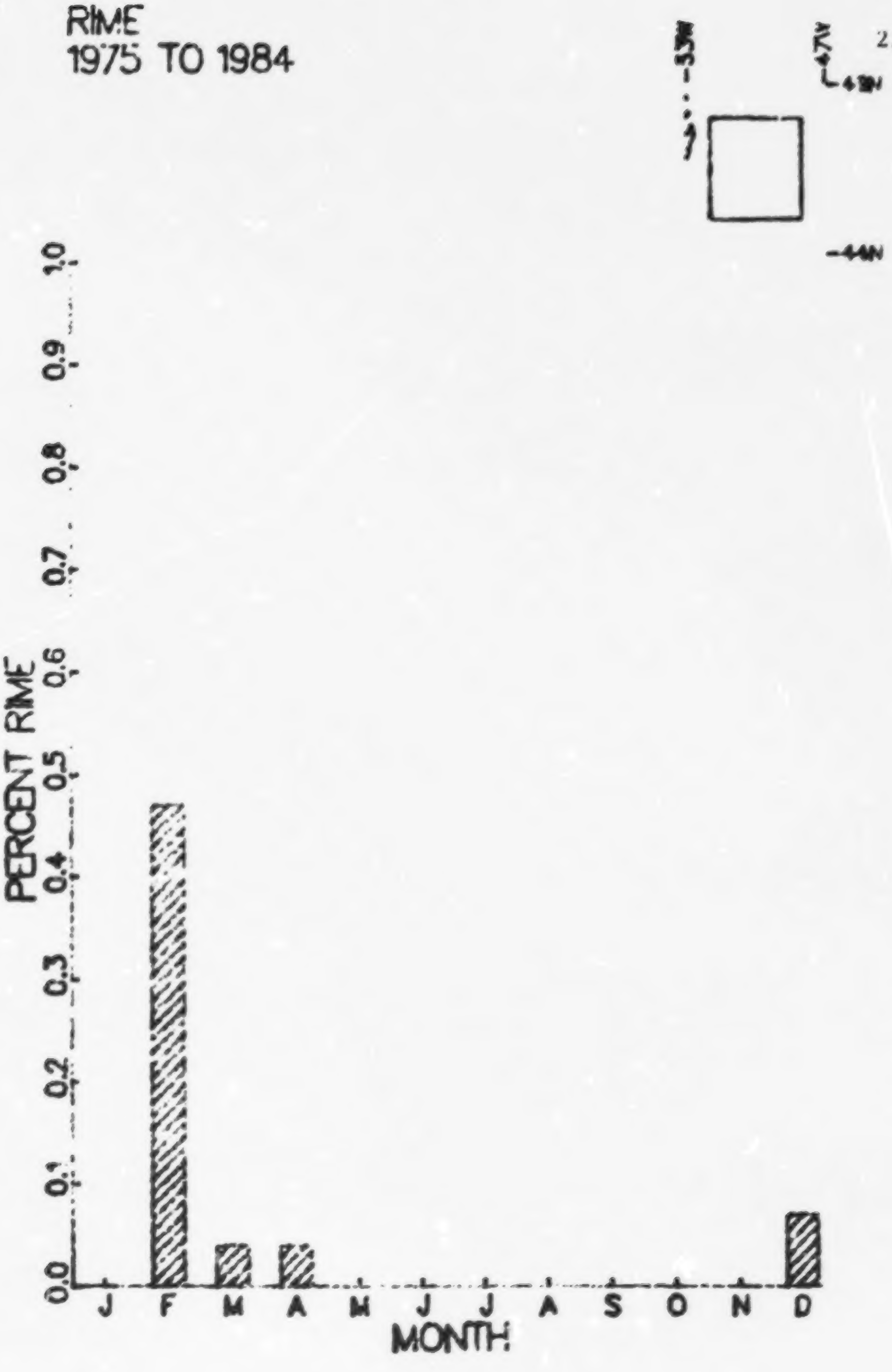


FIGURE 2.41 RIME, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

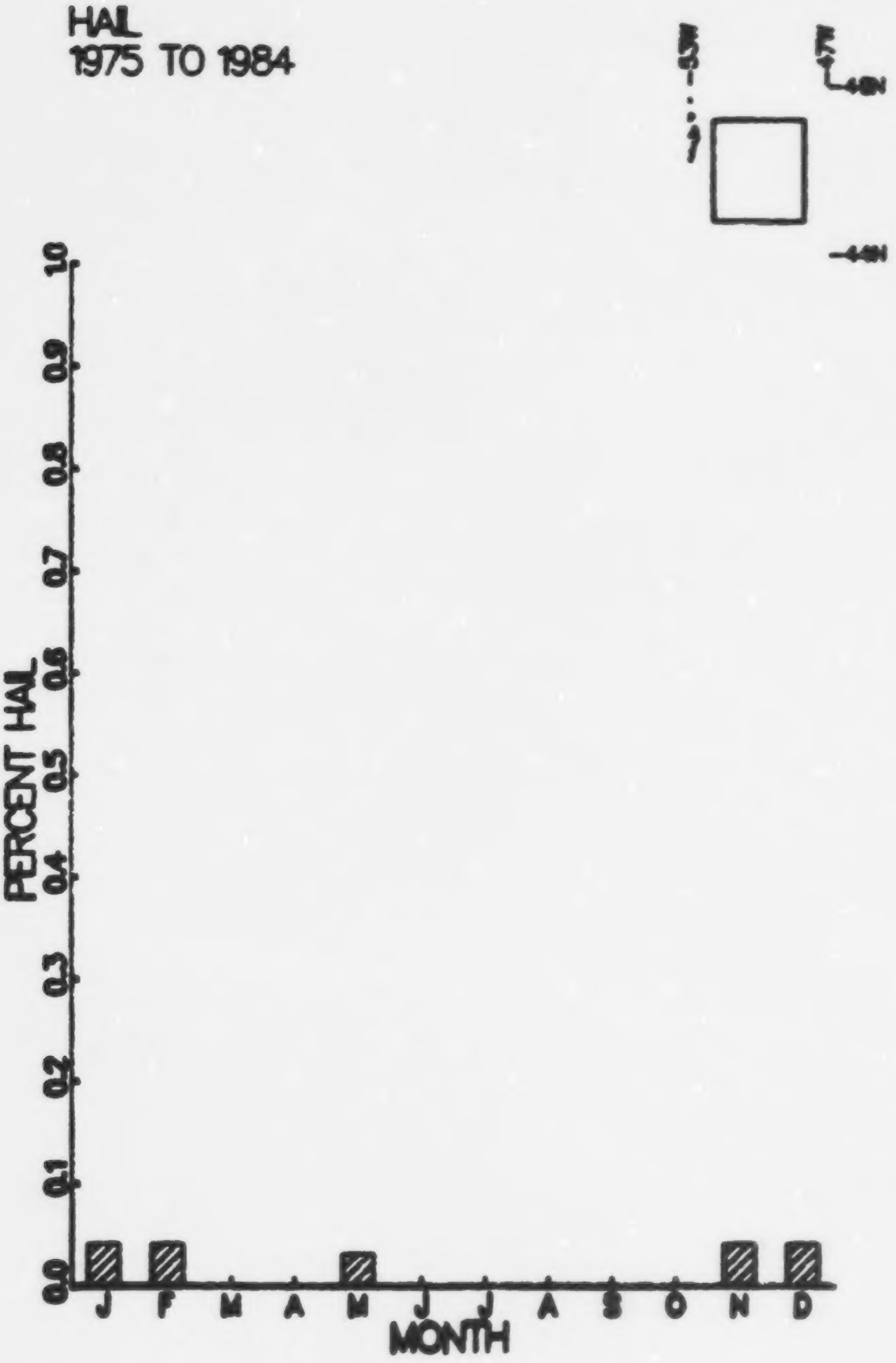


FIGURE 2.42 HAIL, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

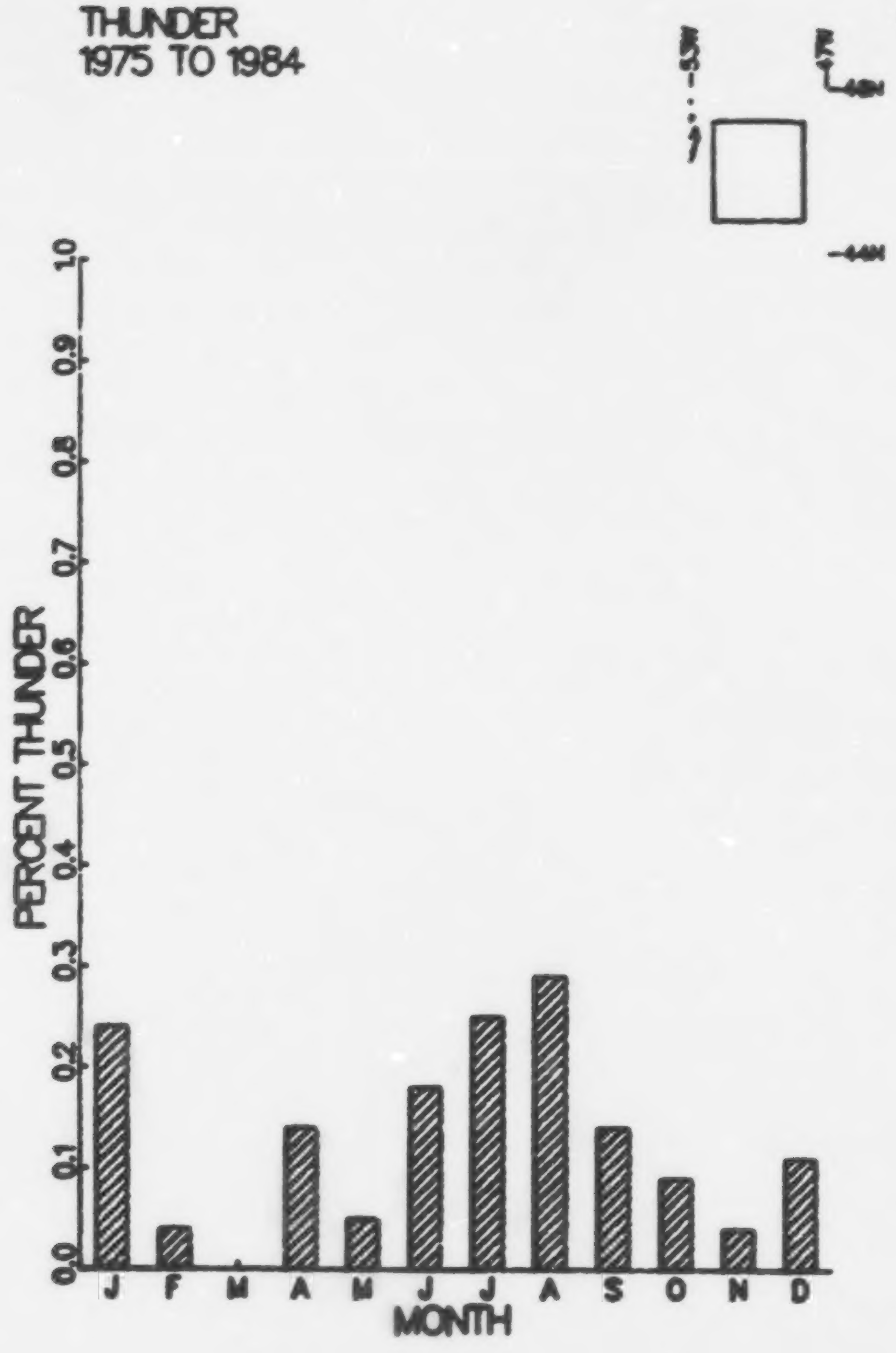


FIGURE 2.43 THUNDER, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

2.1.5.4 Visibility

(a) Historical Data

Visibility relates to both the amount of cloud cover present over the area, and occurence of fog. Figure 2.44 gives the percent cloud cover in the evaluation area, by type, on a monthly basis for the period from 1975 to 1984. April and May are the months with the highest potential for clear skies, and June and July have the highest percentage of potential obscurity. Overcast or obscured sky occurs more than 50% of the time except for September and October. The occurrence of fog and mist, and horizontal visibility are given in Figure 2.45. The most fog prone months are May, June and July (Table 2.9). The number of days with fog, average 46.4 (Hemmerick, 1971). Visibility significantly improves from May to August, while it is much reduced from November through February.

(b) Pertinent Evaluation Data

The data indicate two significant time periods. January to March have a high potential for overcast or obscured skies, a reasonable chance of fog and reduced visibility. June through August have the highest potential for clear skies, while at the same time having a high fog potential. Visiblity tends to be extreme relative to Grand Banks conditions. The first period has conditions that would make it most difficult to detect small objects, while the second presents the best detection weather.

2.1.5.5 Operational Weather

(a) Historical Data

The information presented in this subsection is concerned with special weather data products developed to meet the operational requirements of aircraft and ships. Percent ceiling/horizontal visibility is given in Figure 2.46. These data permit a pilot to operate an aircraft within flexible prescribed limits. Poor flying conditions exist

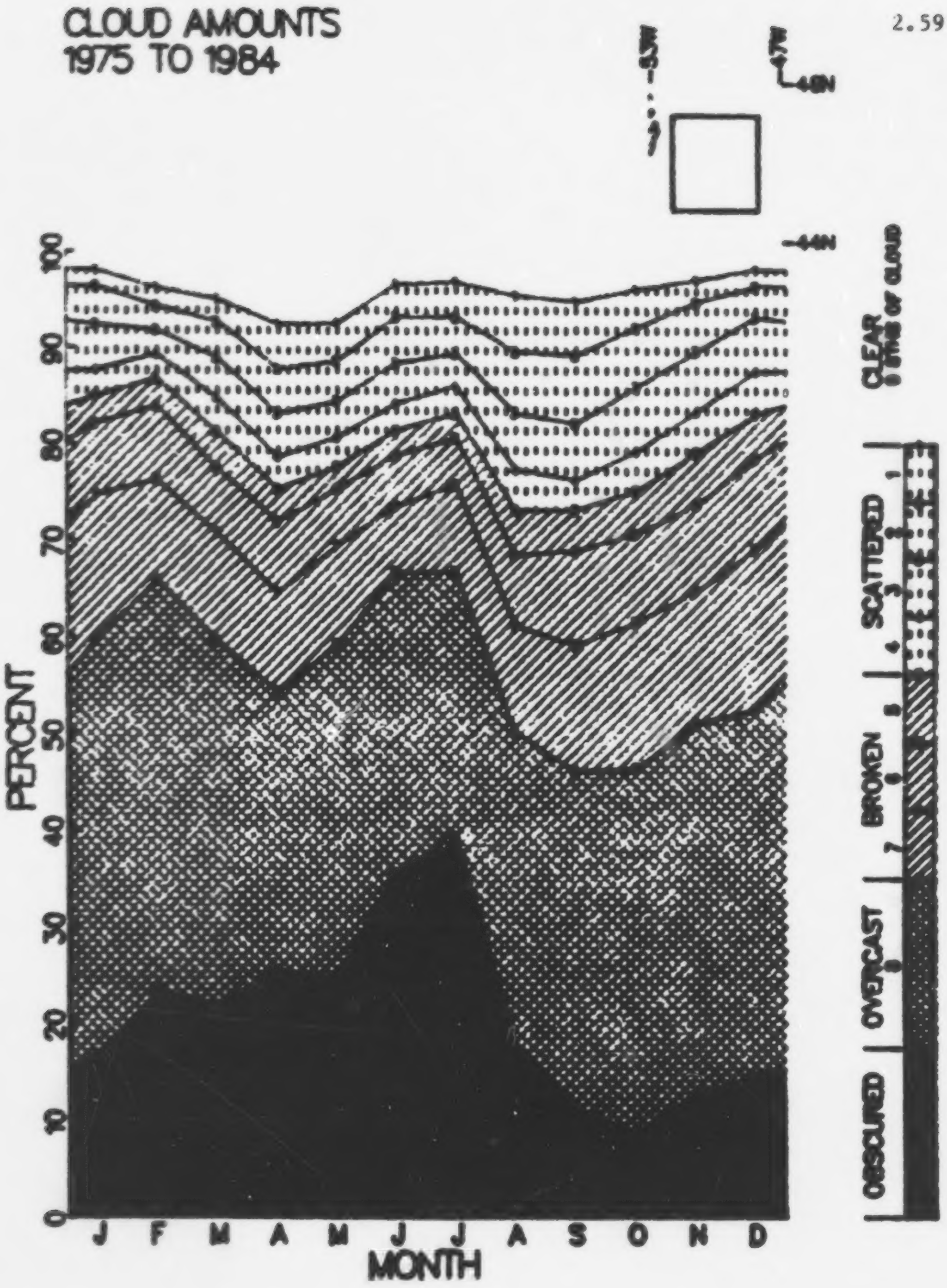


FIGURE 2.44 CLOUD AMOUNTS, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

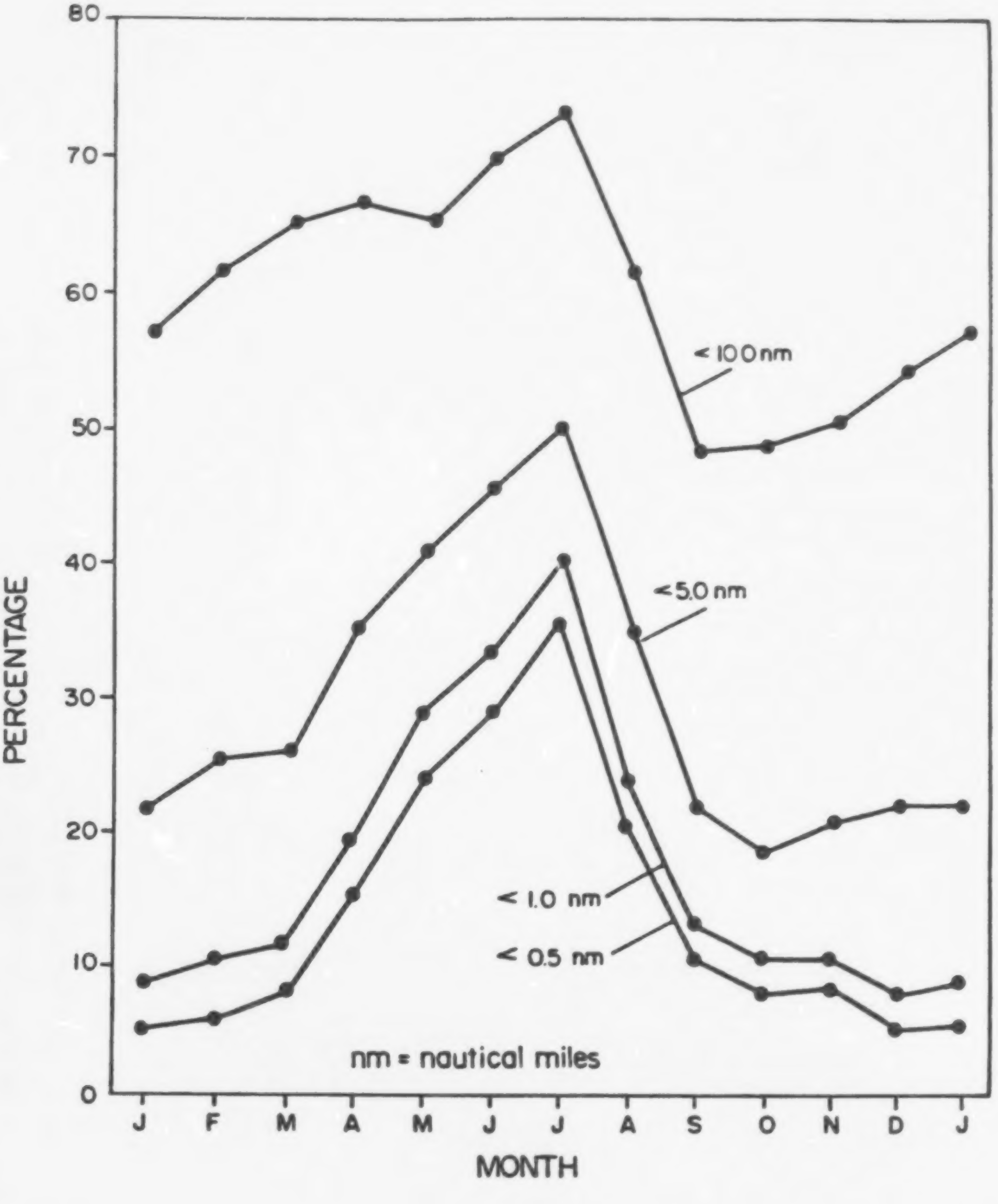


FIGURE 2.45 MONTHLY PERCENTAGE EXCEEDANCE OF VISIBILITY ON THE NORTHERN GRAND BANKS (Petro-Canada Exploration Inc., 1981)

TABLE 2.9

VISIBILITY AND OCCURRENCE OF FOG AND MIST
(PERCENT)
(CANADIAN CLIMATE CENTRE)

MONTH	< 0.5	0.5-1.1	1.1-2.2	2.2-5.4	≥ 5.4	Number Of Observations
January	10.9	13.6	17.2	27.0	73.0	3 333
February	15.2	19.6	26.1	36.7	63.3	2 758
March	18.4	21.9	27.1	38.3	61.7	2 549
April	24.3	27.6	32.3	42.8	57.2	3 415
May	26.9	31.1	35.4	43.9	56.1	4 576
June	38.8	42.3	46.3	53.1	45.9	3 898
July	43.2	27.1	51.0	60.8	39.2	3 123
August	20.6	23.2	27.2	36.8	63.2	3 020
September	11.0	12.4	14.9	24.7	75.3	2 732
October	9.1	10.5	13.7	22.4	77.6	2 902
November	10.6	12.6	16.9	25.9	74.1	3 019
December	11.1	13.5	17.6	26.2	73.8	3 290
	<--Fog--->	<-----Mist------------------------------->				

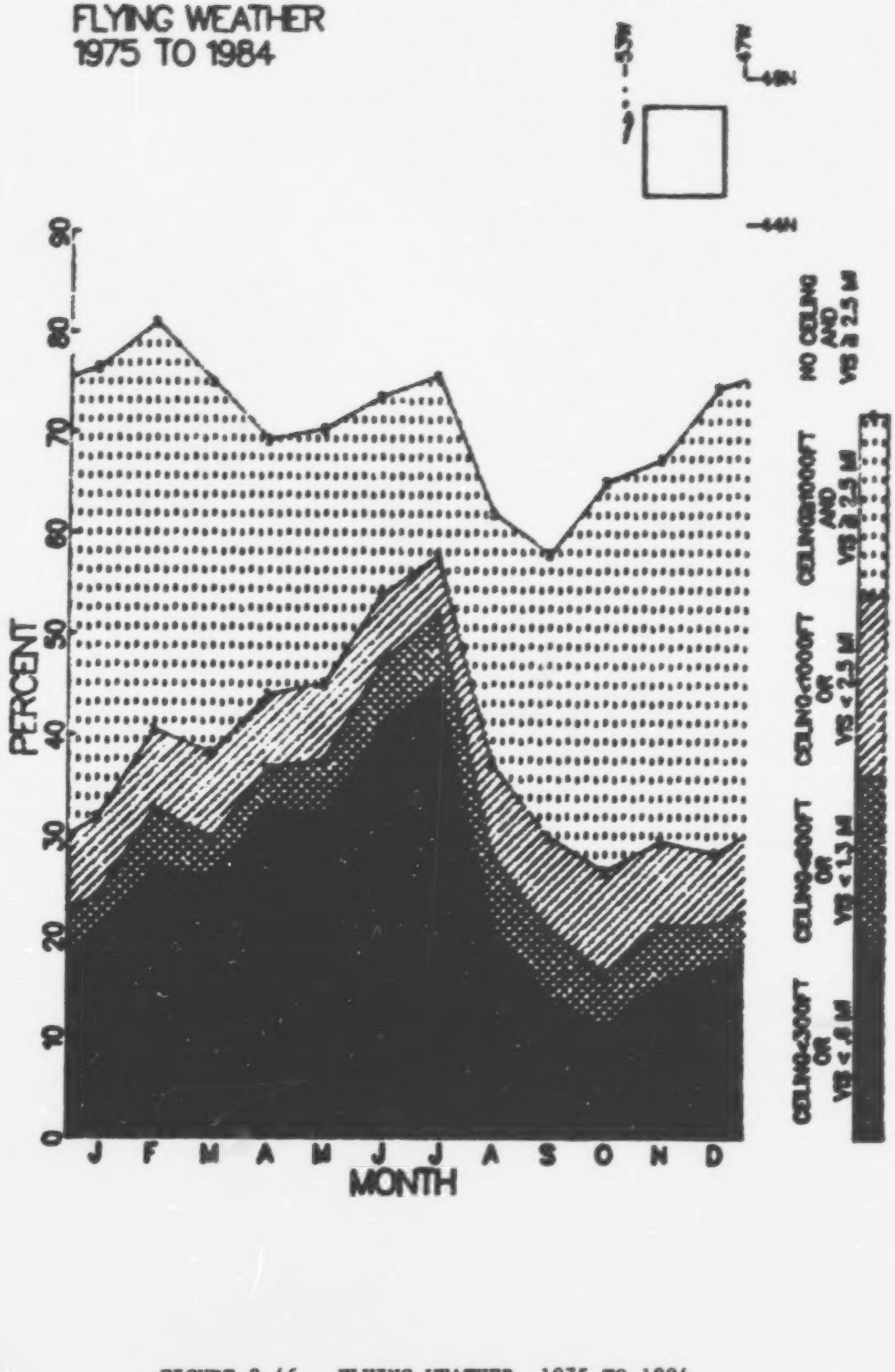


FIGURE 2.46 FLYING WEATHER, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

25 to 30% of the time from January to March. Ceilings and visibility increase poor flying time to over 40% in June and July. Figure 2.47 shows the shipping weather for the area. In reality, it shows the horizontal visibility. Visibility of less than 5 nm occurs for at least 25% of the year. Figure 2.48 give the percent occurrence of freezing spray potential. January and February have the highest potential for heavy or severe freezing spray potential. A concept called 'good shipping weather' is shown in Figure 2.49. It is a combination of visibility in excess of two nm and winds less than 25 kts. Even in the worst month of summer, July, there is almost a 40% chance of good shipping weather.

(b) Pertinent Evaluation Data

These operational products can be used in the design of a field program. They show first-hand that even in the months with the most severe weather conditions it is possible to have a reasonably high percentage of weather during which field evaluations could be carried out.

2.1.5.6 Sea Ice/Icebergs

(a) Historical Data

Sea ice or pack ice frequently cover the study area in various amounts for various periods of time. Figure 2.50 shows the sea ice invasions in the Grand Banks for 1973 to 1976. It can be seen that sea ice can occur from 1 to 23 weeks over the Grand Banks and adjacent areas. Although this is for only three ice seasons, it is representative of the normal incursion patterns over the past several years. Figure 2.51 shows the maximum extent of sea ice and icebergs for several months. This shows that sea ice in concentrations greater than or equal to 1/10 and icebergs and their debris are possible within the study area even in June. More detailed iceberg data are shown in Figure 2.52. Iceberg occurrence is usually stated as the number of

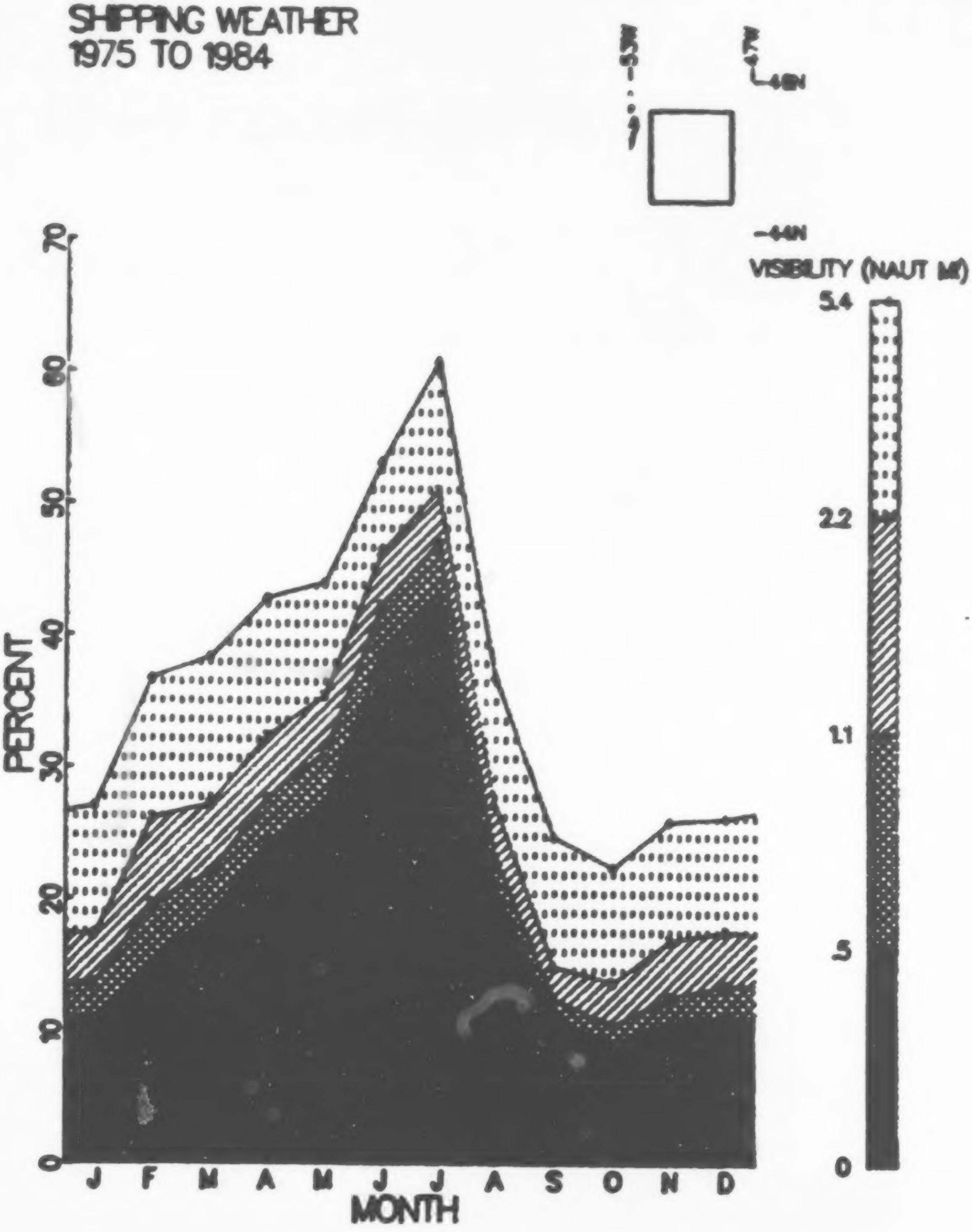


FIGURE 2.47 SHIPPING WEATHER, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

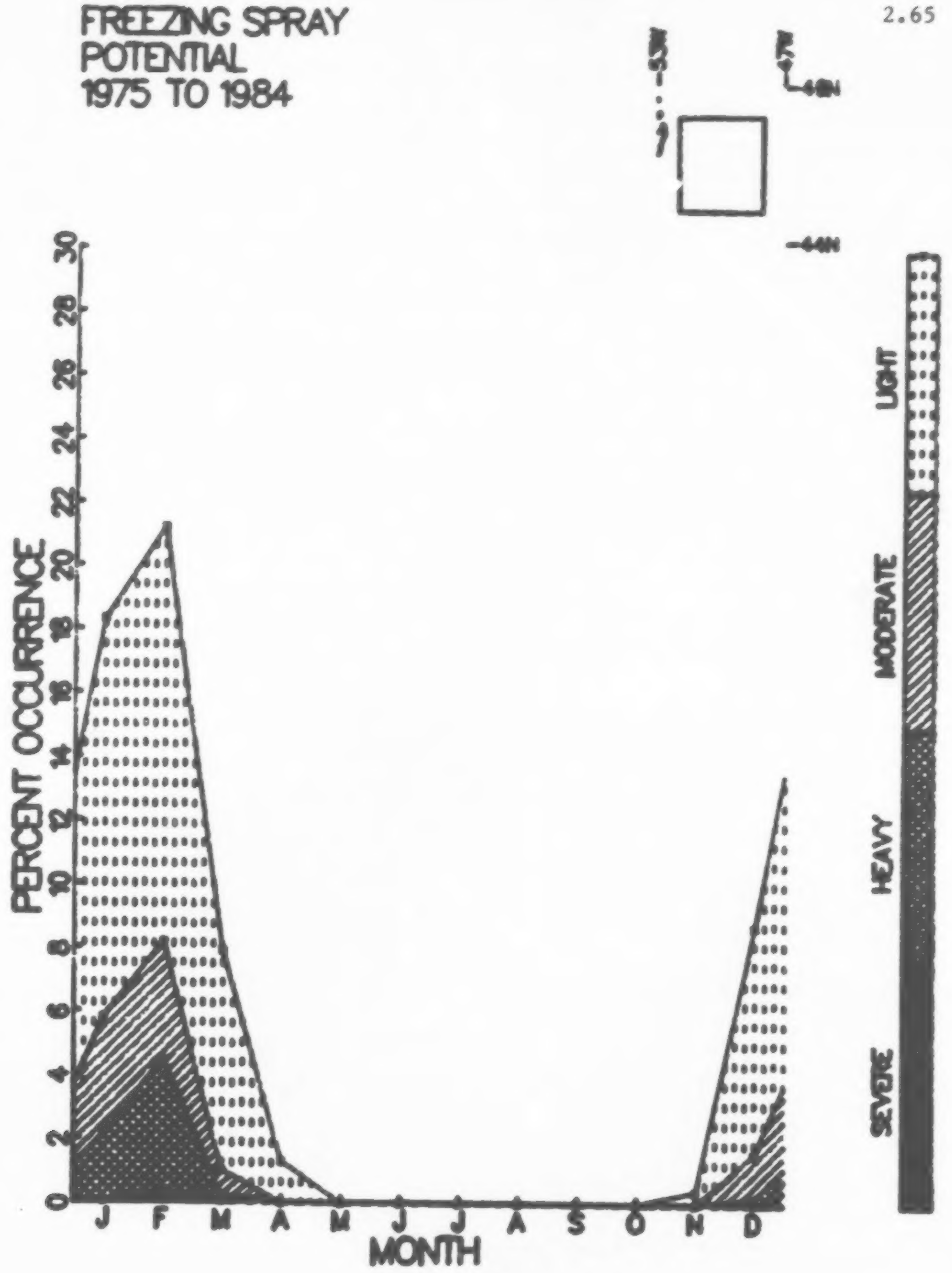


FIGURE 2.48 FREEZING SPRAY POTENTIAL, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

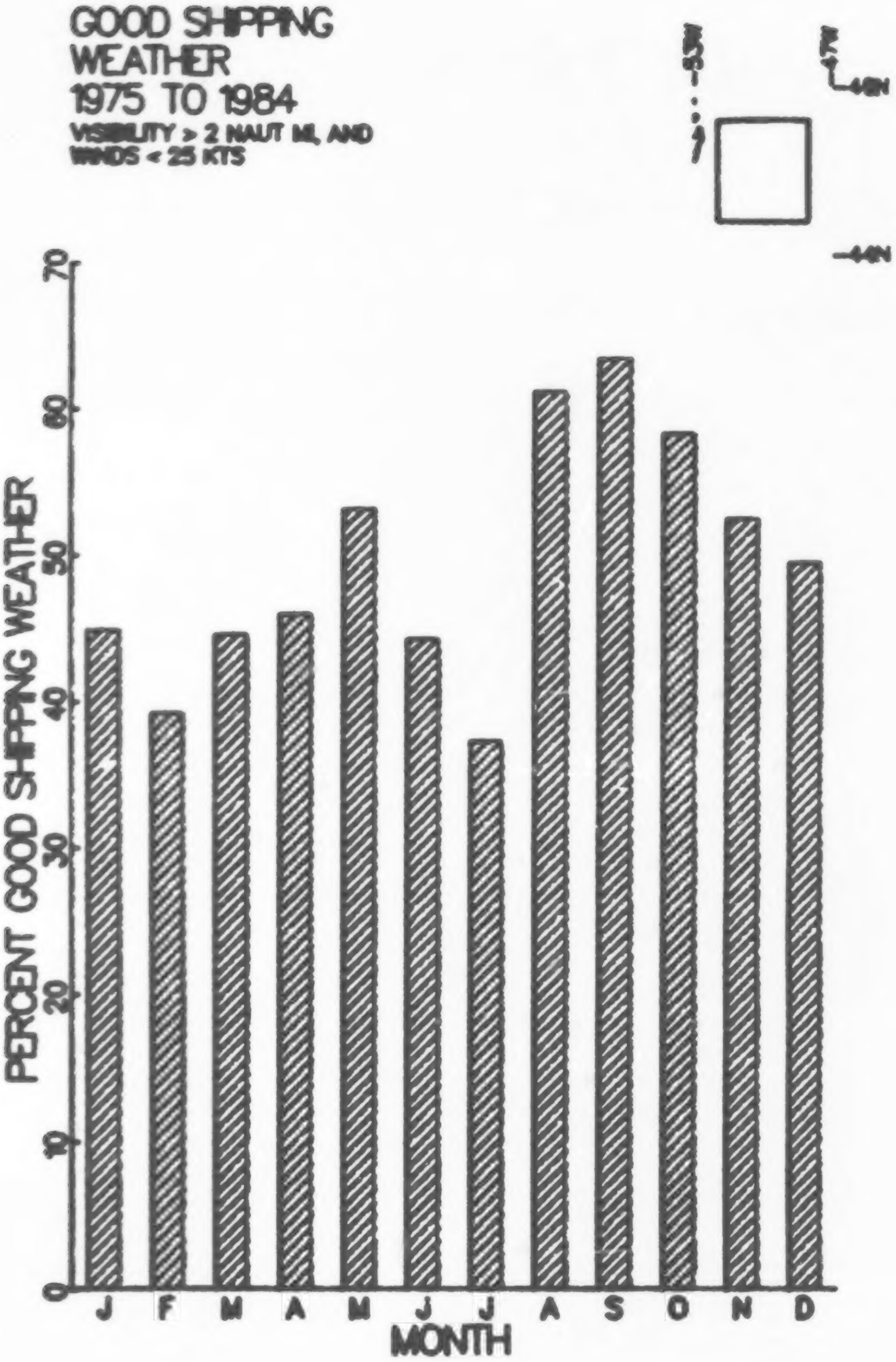


FIGURE 2.49 GOOD SHIPPING WEATHER, 1975 TO 1984

(CANADIAN CLIMATE CENTRE)

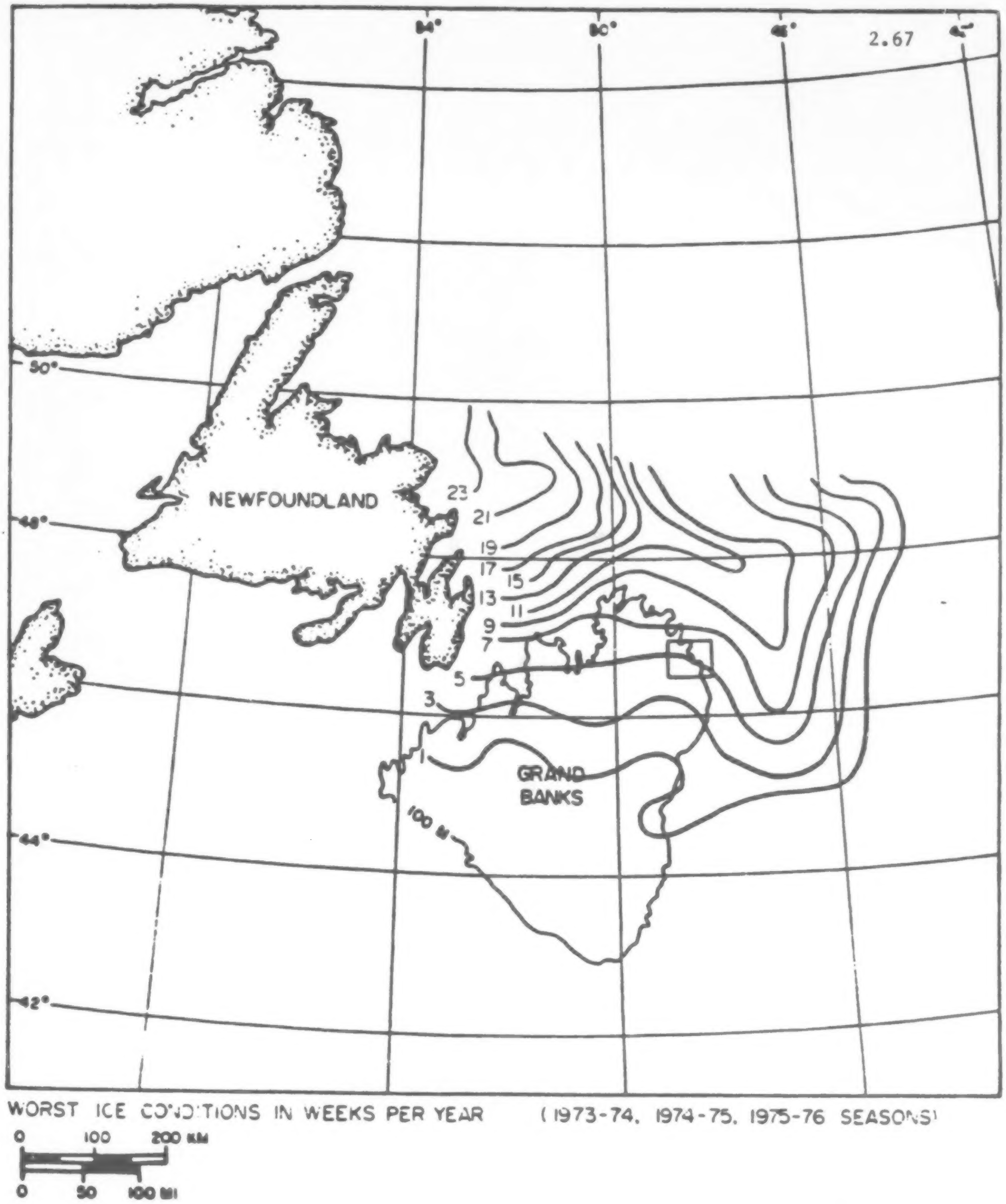

54°
50°
46°
42°
50°
48°
44°
42°
NEWFOUNDLAND
GRAND BANKS
23
21
19
17
15
13
11
9
7
5
3
1
100 m
WORST ICE CONDITIONS IN WEEKS PER YEAR
(1973-74, 1974-75, 1975-76 SEASONS)
0
100
200 KM
0
50
100 MI

FIGURE 2.50 SEA ICE INCURSION ON THE GRAND BANKS (1973-76)
(Newfoundland Petroleum Directorate)

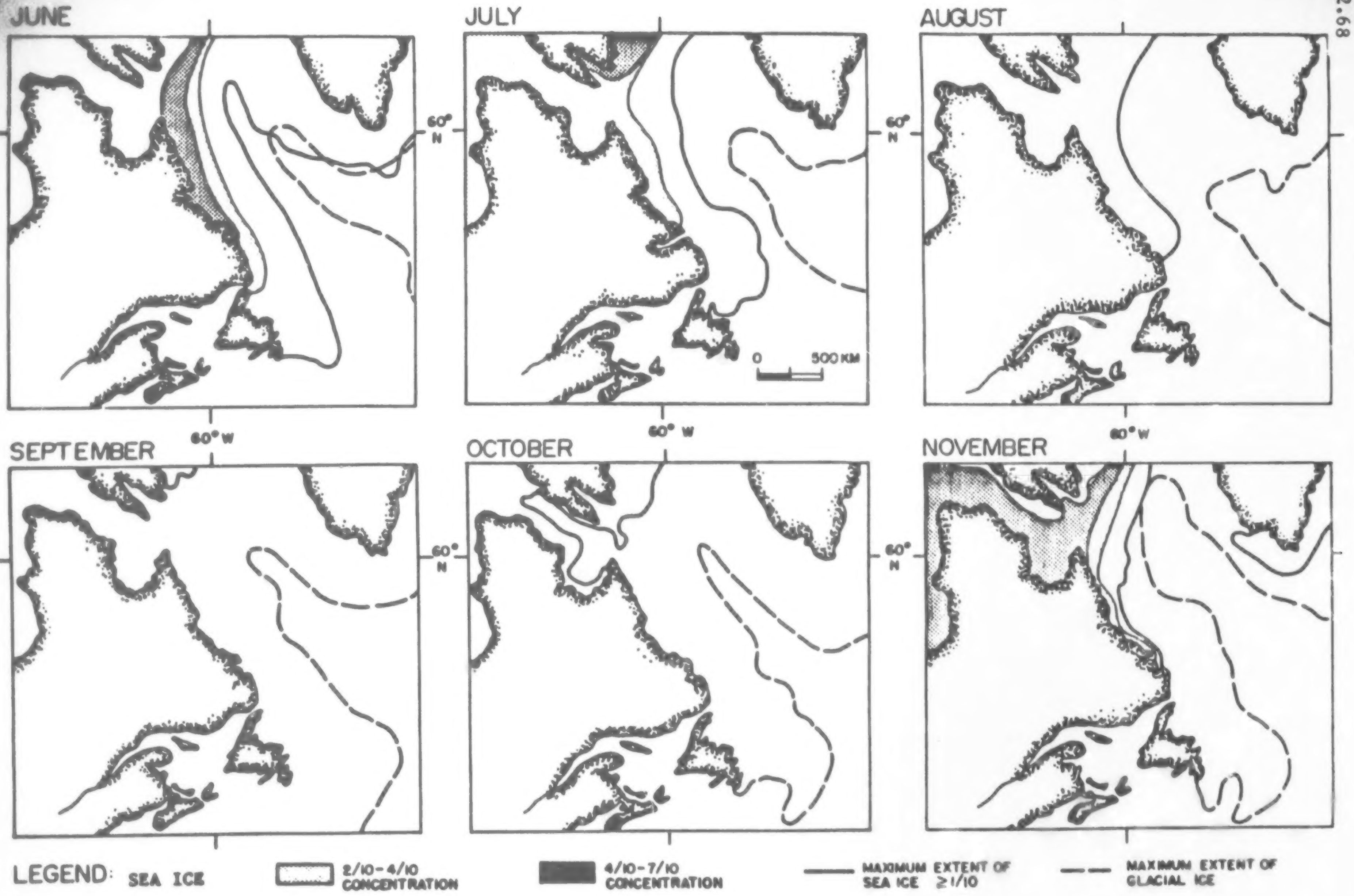

JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
60° N
60° W
0
500 KM
LEGEND: SEA ICE
2/10-4/10 CONCENTRATION
4/10-7/10 CONCENTRATION
MAXIMUM EXTENT OF SEA ICE ≥1/10
MAXIMUM EXTENT OF GLACIAL ICE

FIGURE 2.51 SEA ICE CONCENTRATION - OFFSHORE LABRADOR
(Meserve JM.,1974)

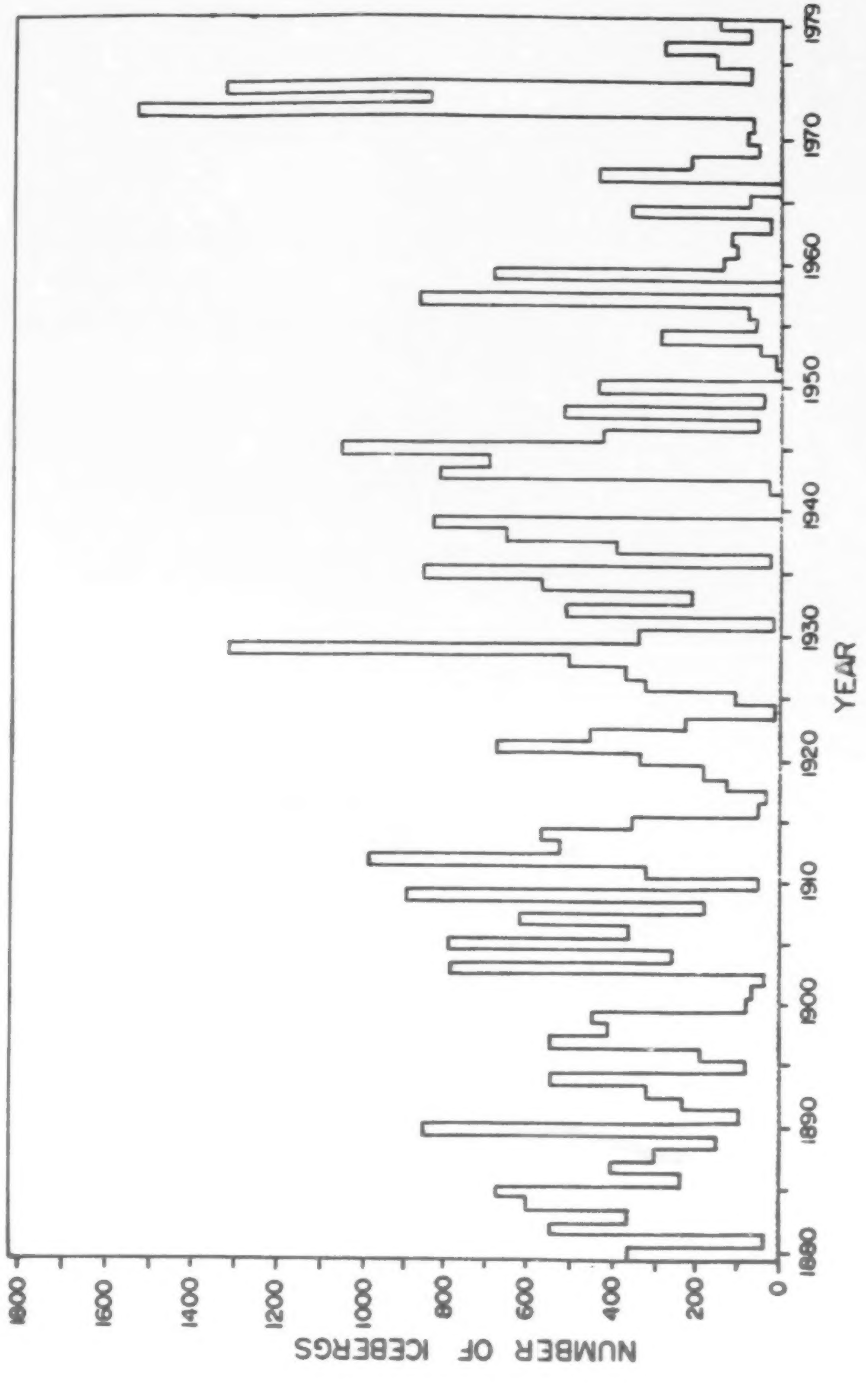


FIGURE 2.52 HISTORICAL ICEBERG DRIVE SOUTH OF 48°N
(Petro-Canada Exploration Inc., 1981)

icebergs that occur south of Latitude 48°N. This arbitrary boundary is set because of the northern limit of operations of the International Ice Patrol. They are responsible for defining the southern limits of all iceberg hazards and, by convention, have established 48°N as the northern boundary. Figure 2.52 shows the yearly distribution for the past 100 years, while Figure 2.53 shows the distribution of sightings for a one-year period (Petro-Canada, 1981) with April and May the peak months. Figure 2.54 shows the mean monthly occurrences and monthly maxima for icebergs south of 48°N. Southern monthly limits for March to June are shown in Figures 2.55 to 2.58, respectively, for the period 1946 to 1971 (Markham, 1980). Using the International Ice Patrol yearly reports, it can be shown that the iceberg season length is generally from March to July. The longest season was nine months (December 1982 to August 1983), and the shortest season was zero months (1965-1966). The average number of iceberg sightings per season up to 1975 was 391. As a result of more reporting due to offshore exploration activity, it appears that the maximum of 1587 seen in 1971-72 may be the yearly maximum for the general area, although the hypothesis has not been verified. Icebergs also range in size. Table 2.10 gives percent exceedance for mass and draft for icebergs on the Grand Banks.

(b) Pertinent Evaluation Data

This information shows that both sea ice and icebergs will occur in the study area as false alarm targets. Sea ice greater than 1/10 concentration is considered pack ice, and targets in pack ice are not part of this evaluation.

2.2 Target Information

A large variety of objects are potential search and rescue or false alarm targets. It was decided that an initial target classification was necessary and that it should be based on size. The United

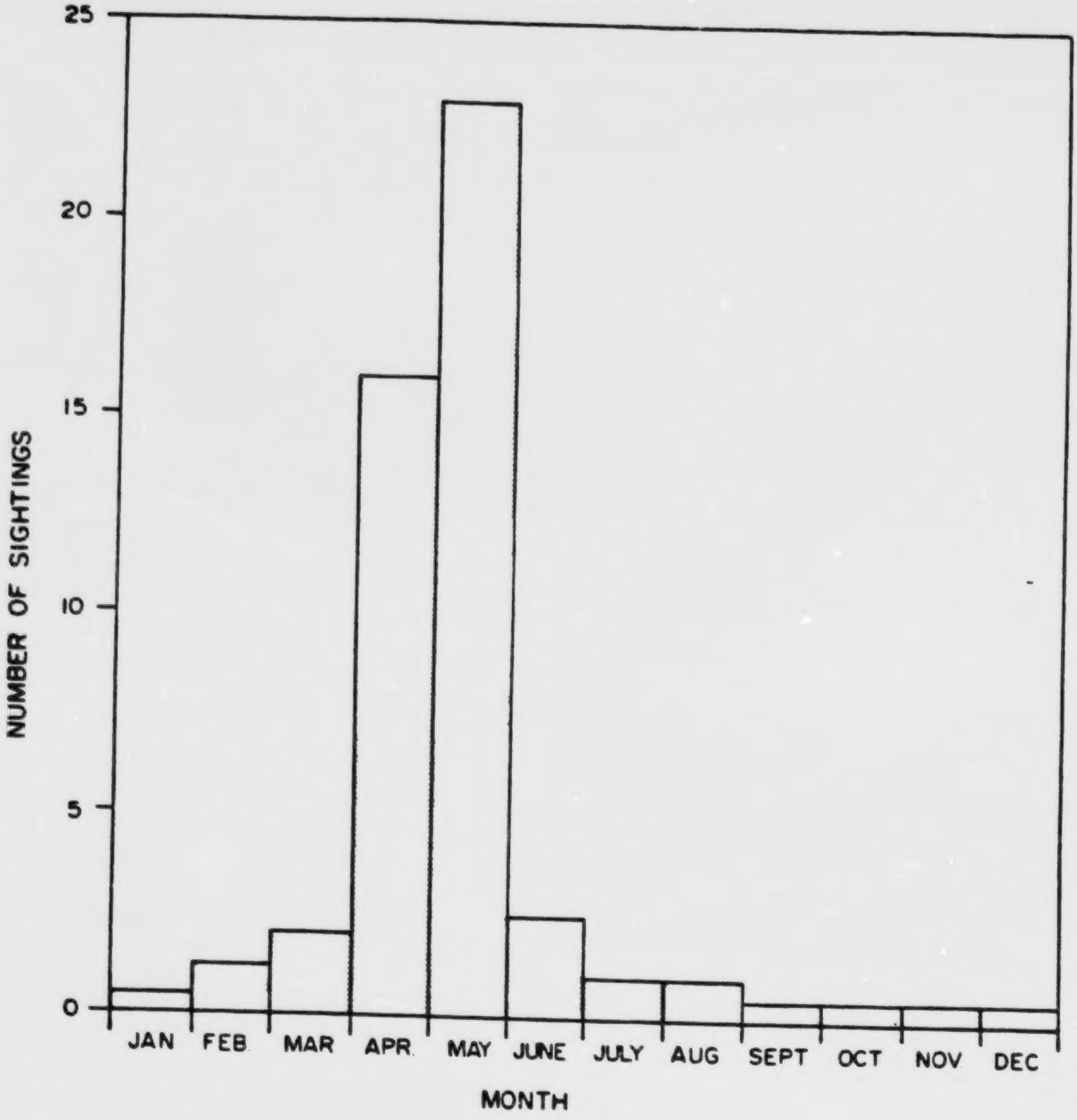


FIGURE 2.53 MONTHLY AVERAGE INCIDENCE OF ICEBERGS ON THE GRAND BANKS (46°-47° N, 48°-49° W) (Petro-Canada Exploration Inc., 1981)

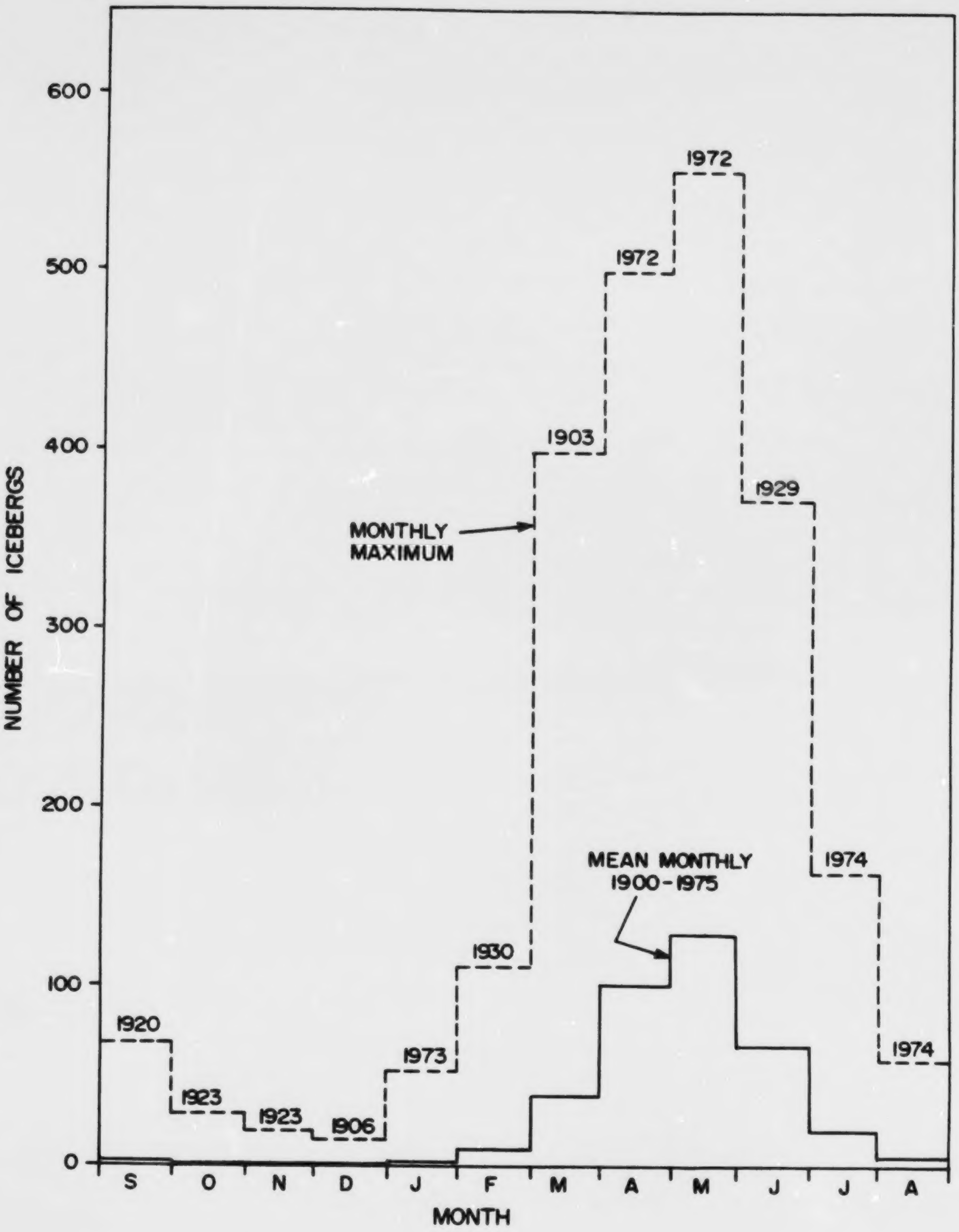


FIGURE 2.54 MONTHLY ICEBERG FREQUENCY SOUTH OF 48°N

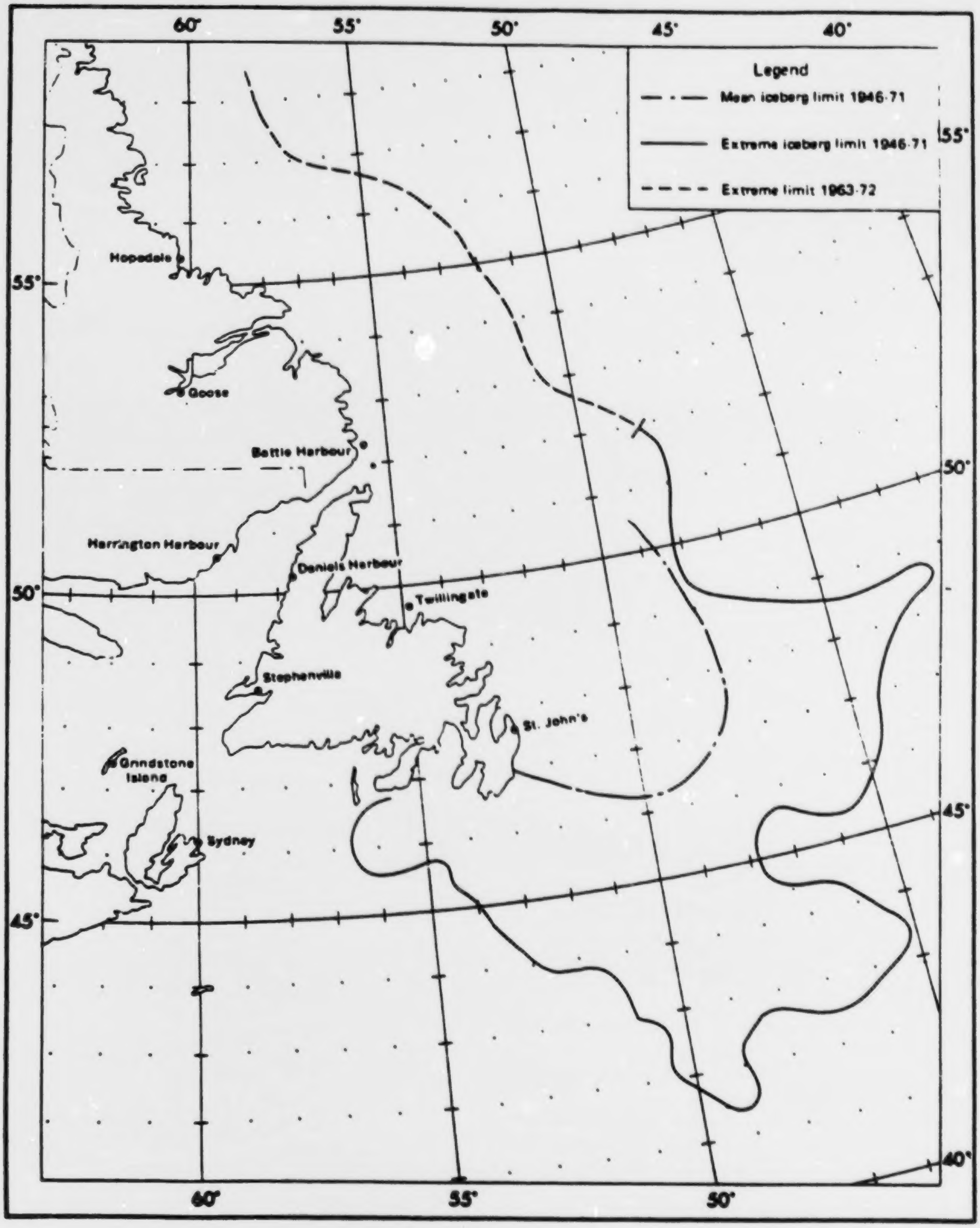

Legend
Mean iceberg limit 1946-71
Extreme iceberg limit 1946-71
Extreme limit 1963-72
60°
55°
50°
45°
40°
Hopedale
Goose
Battle Harbour
Harrington Harbour
Daniels Harbour
Twillingate
Stephenville
St. John's
Grindstone Island
Sydney

FIGURE 2.55 MARCH - MONTHLY ICEBERG LIMITS
(FROM INTERNATIONAL ICE PATROL DATA)
(Markham, 1980)

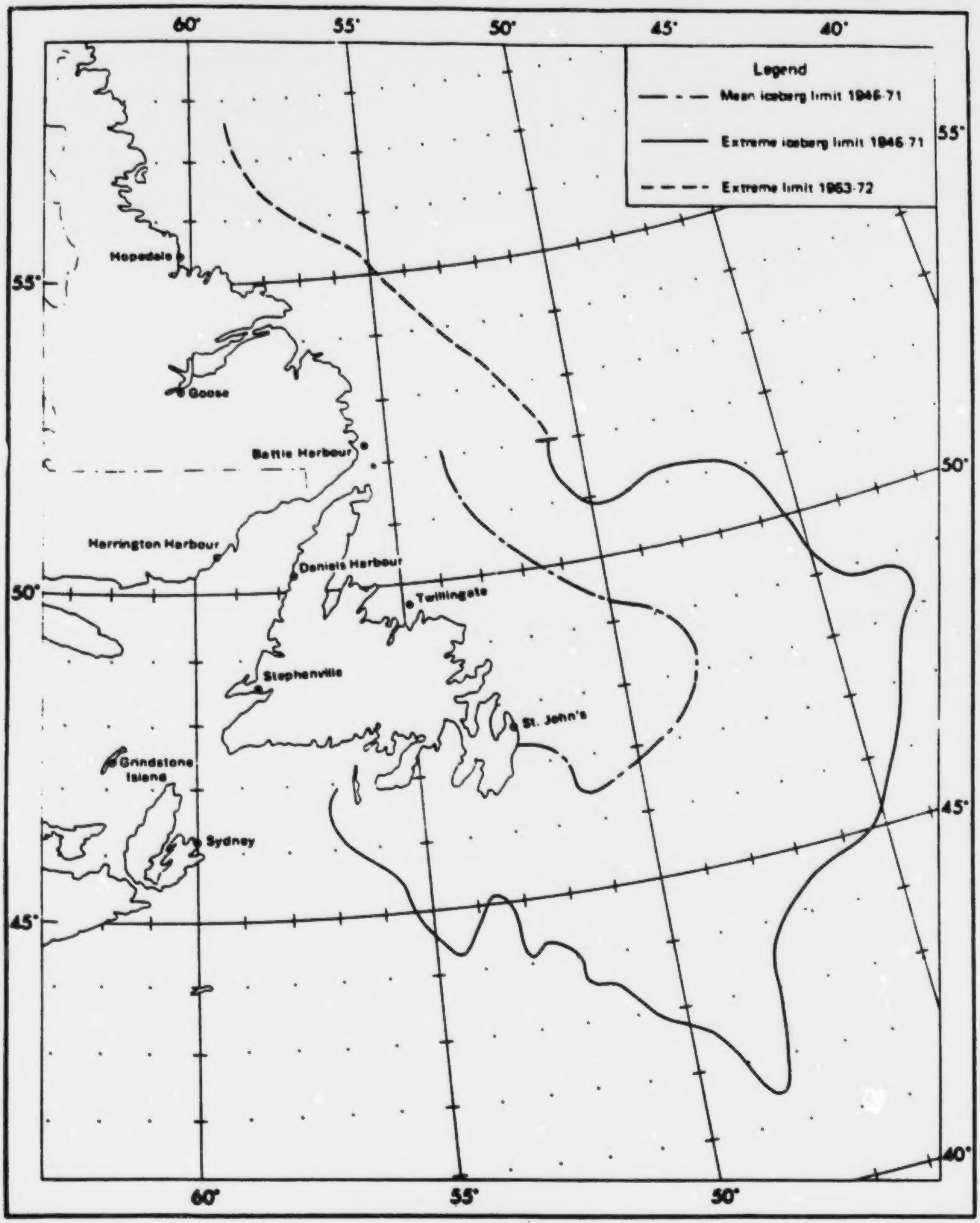

60°
55°
50°
45°
40°
Legend
Mean iceberg limit 1946-71
Extreme iceberg limit 1946-71
Extreme limit 1963-72
Hopedale
Goose
Battle Harbour
Harrington Harbour
Daniels Harbour
Twillingate
Stephenville
St. John's
Grindstone Island
Sydney

FIGURE 2.56 APRIL - MONTHLY ICEBERG LIMITS
(FROM INTERNATIONAL ICE PATROL DATA)
(Markham, 1980)

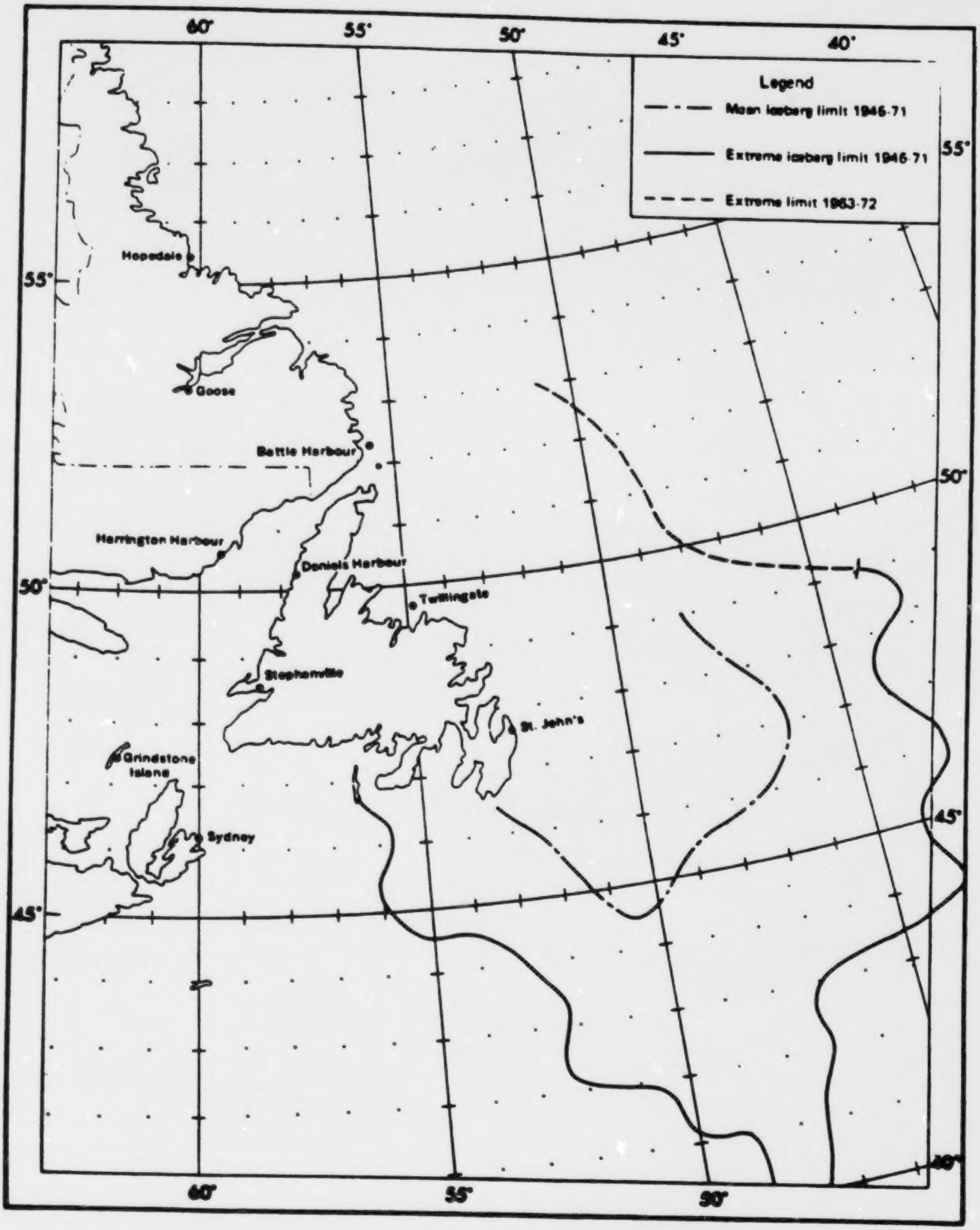

60°
55°
50°
45°
40°
Legend
Mean iceberg limit 1946-71
Extreme iceberg limit 1946-71
Extreme limit 1963-72
55°
50°
45°
Hopedale
Goose
Battle Harbour
Harrington Harbour
Daniels Harbour
Twillingate
Stephenville
St. John's
Grindstone Island
Sydney
55°
50°
45°
40°
60°
55°
50°

FIGURE 2.57 MAY - MONTHLY ICEBERG LIMITS
(FROM INTERNATIONAL ICE PATROL DATA)
(Markham, 1980)

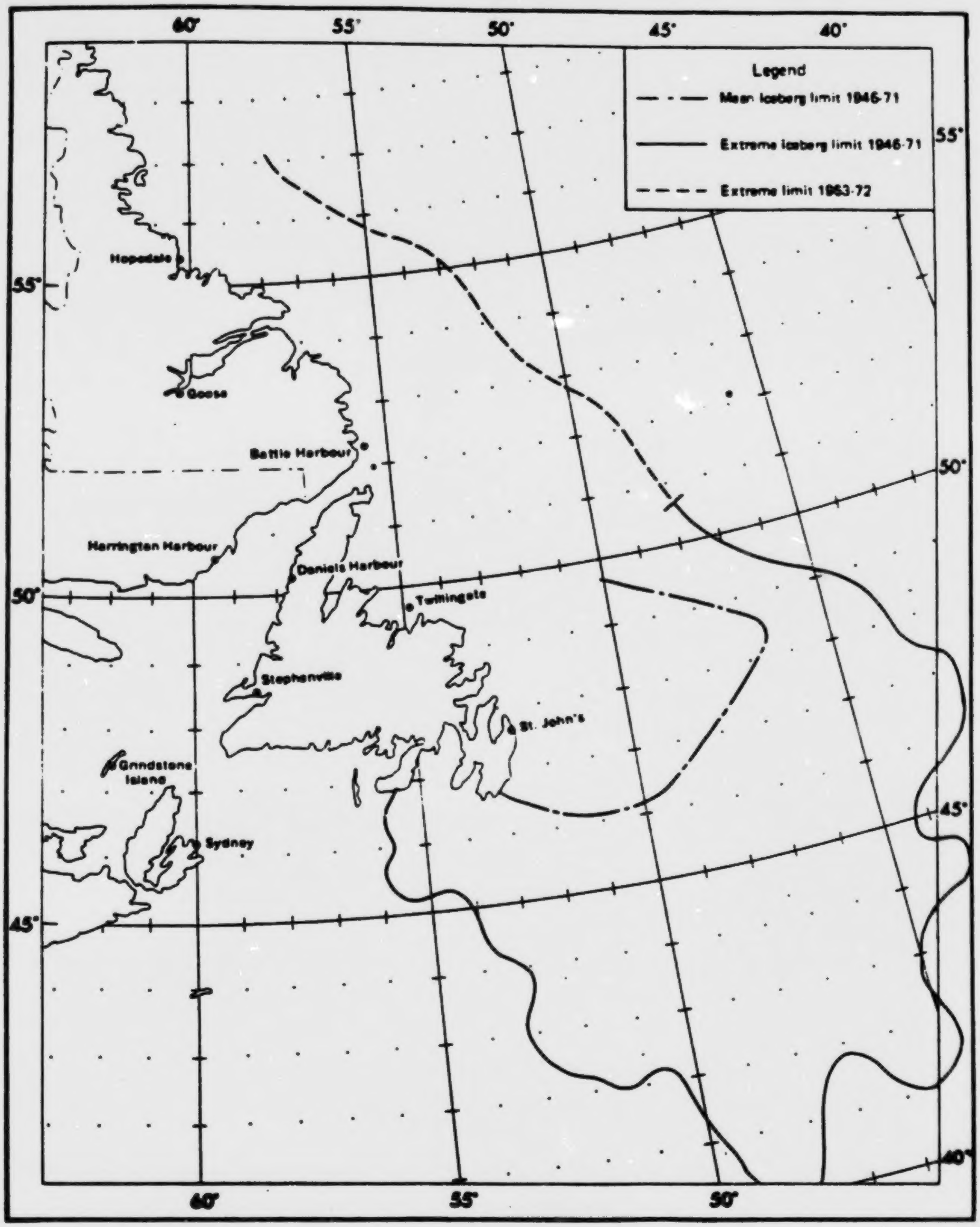

Legend
Mean iceberg limit 1946-71
Extreme iceberg limit 1946-71
Extreme limit 1963-72
60°
55°
50°
45°
40°
Hopedale
Goose
Battle Harbour
Harrington Harbour
Daniels Harbour
Twillingate
Stephenville
St. John's
Grindstone Island
Sydney

FIGURE 2.58 JUNE - MONTHLY ICEBERG LIMITS
(FROM INTERNATIONAL ICE PATROL DATA)
(Markham, 1980)

TABLE 2.10

PERCENTAGE EXCEEDANCE OF ICEBERGS ON THE GRAND BANKS

[Hotzel and Miller, 1983]

PERCENT EXCEEDANCE	MASS ($\times 10^3$ tonnes)	DRAFT (m)
50	11	29
25	202	57
15	322	64
10	509	71
5	799	80
2	1 240	87

States Coast Guard (U.S.C.G.), in their recent search and rescue evaluation program, used a size classification, and added descriptive identifiers. Their size categories, however, are not rigid; for example, a 16' boat could be a 15 to 20' boat. Their classification categories as as follows:

(a) Boats, 41' or larger (approximately 12 m).
(b) Boats, 16' (approximately 5 m).
(c) Life Rafts, 4- and 7-man (approximately 2 to 3 m).
(d) Persons in water (PIWs).

The 41' boat classification category includes sailing yachts, cabin cruisers, and small fishing vessels, and the 16' boat category includes most of the other pleasure boats of substantial or family size. The life rafts and small two- or three-man boats are approximately of the same size.

With respect to this study, the various target sizes were examined. A cursory division of target categories was made as follows:

(a) < 1 m.
(b) 1 m to 5 m.
(c) 5 m to 15 m.
(d) > 15 m.

Examination of the various targets showed that while this was one method of categorizing targets, other factors such as material properties and geometrical shape might necessitate a re-examination during the evaluation. This, of course, would depend on the literature review and probability-of-detection data extracted or developed.

A second consideration was the occurrence of target types. Using environmental as well as geographic criteria, it was decided that the following activity zones could be defined and that these zones could be characterized by the most expected target type:

1. 0 to 3 mi. offshore - pleasure boats, nearshore fishing operations.
2. 3 to 12 mi. offshore - larger pleasure boats, mid-size fishing operations.
3. 12 to 50 mi. offshore - nearshore fishing fleet.
4. > 50 mi. - deep sea fishing fleet, petroleum and geophysical exploration.

The major transgressors of these zones would be downed aircraft, approaches to harbours, major shipping routes and PIWs. For convenience, the targets will be discussed in terms of the above as they are general classification criteria.

2.2.1 Very Small Targets (<1 m)

A certain number of man-made targets fall into this category. These incude buoys, rescue lights and beacons. Table 2.11 lists these classes and subclasses and provides information on size, shape, structure, colour and mode of operation. Other targets which should be included in this category are PIWs, military targets such as periscopes, and small pieces of debris. These are not conducive to standardization and are not tabularized. With respect to PIWs, consideration must be given to life vests, but not to some life support suits as they are covered in the next larger class. For discussion purposes, PIWs, with or without suits, will be considered in this group even though some life support systems make them larger in size.

2.2.2 Small Targets (1 to 5 m)

This category includes a number of man-made targets and marine life targets. Table 2.12 lists the major generalized man-made targets such as life rafts, buoys and safety clothing. Table 2.13 lists the various expected types of animal life. Schools of pelagic fish might also be considered in this class, as would crash debris, and small pollution spills and slicks.

2.2.3 Medium Targets (5 to 15 m)

This size category also contains several types of man-made and animal life targets. Table 2.14 gives information pertaining to rigid and inflexible liferafts. Table 2.15 gives information about the animal life. Other targets in this category include small fishing boats such as dories, skiffs and other open fishing boats, and pleasure craft such as small sailboats and outboard motor boats. These can be either wooden or metallic. Two other targets that can be considered in this category are oil slicks and ghost nets (free floating, loose fish nets) which are common in Newfoundland waters.

TABLE 2.11

VERY SMALL MAN-MADE TARGETS (< 1 m)

OBJECTS	DIMENSIONS (m)				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	Freeboard	Draft	Length	Beam				Passive Devices	Active Devices	
1. EMERGENCY POSITION-INDICATING RADIO BEACONS										
a. Class A Type			0.4	0.1 (dia)	Cylindrical	Plastic/ Fibreglass	Red/ Orange		X	200-300 mile range. Automat. activated.
b. Class B Type			0.4	0.1 (dia)	Cylindrical	Plastic/ Fibreglass	Red/ Orange		X	200-300 mile range. Manually Operated.
c. Class C Type			0.4	0.1 (dia)	Cylindrical	Plastic/ Fibreglass	Red/ Orange		Flashing light	20 mile range. Manually operated.
2. RESCUE LIGHTS										
a. Strobe (anti-collision)			0.2	0.12 (dia)	Cylindrical	Plastic/ Fibreglass	White/ Orange/ Red		X	Manually activated. Peak brightness 4 million candle power.
b. Air/Marker Light			0.35	0.1 (dia)	Cylindrical	Plastic/ Fibreglass	White/ Orange/ Red		X	Auto. or man. activ. Up to 360° visibility for 15 miles at 500 ft.
c. Personal Rescue Lt.			0.18	0.14	Cylindrical	Plastic/ Fibreglass	White/ Orange/ Red		X	360° visibility over 2 miles. Automatic. Activated.
d. Signal Marker			0.2	0.18	Cylindrical	Plastic/ Fibreglass	White/ Orange/ Red		X	3 million peak lumens/ flash. Automatic. activated. Oceanograph./geodetic survey buoys.

TABLE 2.11

VERY SMALL MAN-MADE OBJECTS (< 1 m) Cont'd)

OBJECTS	DIMENSIONS (m)				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	Freeboard	Draft	Length	Beam				Passive Devices	Active Devices	
3. BUOYS										
a. Environmental (Wave-riders)	0.6	0.6	1.2		Spherical	Steel		X	X	Flashes 3-4 times/ 20 second period.
b. Fishing Buoys	0.5 - 0.6	0.4 - 0.5	1 (diam)		Spherical	Vinyl/ Plastic	Orange	X		Some may have radar reflectors mounted on aluminum poles.
c. Fishing Markers	0.1	0.1	0.2 (diam)		Spherical	Vinyl/ Plastic	Orange	X		

TABLE 2.12

SMALL MAN-MADE TARGETS (1 - 5 m)

OBJECTS	DIMENSIONS (m)				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	Freeboard	Draft	Length	Beam				Passive Devices	Active Devices	
1. LIFERAFT										
a. Inflatable Liferaft	1.35		2.69	2.69	Round	Nylon Butyl ribber coating	Orange	Reflec-tive strips Signal mirror	Exterior lighting Whistle Para-chute distress flare Hand flares	10 man capacity.
b. Enclosed Rigid			3.35	2.3	Elongated	Fibreglass reinforced plastic	Orange	Reflec-tive tape	Search-lights VHF radio	14 man capacity.
2. BUOYS										
a. Naviga-tional	1.5	1.5 - 2.0	2.0 (diam)		Conical	Steel	Red		Flashing light	
b. Environ-mental (Hermes)	0.6	1.5	1.0 (diam)		Spherical	Fibreglass/ Aluminum	Yellow/ Orange			No markers and half are set adrift.
c. Anchor Buoys	0.5 - 1	0.5 - 1.0	2 - 3 (diam)	1-1.5	Tubular	Steel	Varies			No marker or lights.

TABLE 2.12

SMALL MAN-MADE TARGETS (1 - 5 m) Cont'd

OBJECTS	DIMENSIONS (m)				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	Freeboard	Draft	Length	Beam				Passive Devices	Active Devices	
d. Marker (Shipping Aids)	4.5	4.5	1.4 - 2.9 (diam)			Steel	Red Green Yellow Orange White	Radar reflector	Flashing lights (red, green, yellow)	About 430 buoys around Newfoundland.
					3. SAFETY CLOTHING					
a. Exposure Suit			1.8 - 2.4		N/A	5 mm thick neoprene Metallic front zipper	Orange	Retro-reflective tape on hood and shouldrs		
b. Survival Suit			1.8 - 2.4		N/A	Polyurethane Metallic front zipper	Orange	50x100mm reflective tape on upper arms 50x200mm reflective tape on hood	Chemical light stick in sleeve	Requires additional vest.

TABLE 2.12

SMALL MAN-MADE TARGETS (1 - 5 m) Cont'd)

OBJECTS	DIMENSIONS (m)				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	Freeboard	Draft	Length	Beam				Passive Devices	Active Devices	
c. Immersion Suit			1.8 - 2.4		N/A	Dry foam Neoprene (5mm thick)	Orange	Fluorescent fabric Reflective tape on shouldrs & hood	Safety light Whistle	Self-buoyant.
d. Survival Suit			1.8 - 2.4		N/A	Outer PVC coating w/ inner PVC Foam Nylon Fabric	Orange	Fluorescent hood Reflective tape	Whistle Safety strobe light	
e. Diving Suit			1.8 - 2.4		N/A	Neoprene foam	Black	Stainless steel diving helmet		

TABLE 2.13

SMALL ANIMAL LIFE TARGETS
(1 m to 5 m)

TYPE	DESCRIPTION
SEALS	- Warm-blooded, air breathing mammals.
Harbour Seal	- Found in groups of several hundred, late summer and fall. - Bluish-grey coat, white belly. - Pup 0.8 m long, weighing 20 lbs. - Adult 1.5 m long, 200 lbs.
Harp Seal	- Breeding concentration of several hundred thousand off southern Labrador and Gulf of St. Lawrence. - Newborn whitecoats average 0.9 m, 15 lbs. - Adults average 1.6 m, 300 lbs.
Hooded Seal	- Congregates in large scattered groups during breeding season. - Found in pack ice off Labrador Coast, Northeast Newfoundland, and the Gulf of St. Lawrence. - Pups average 0.9 m. - Adult male averages 2.3 m, 700 lbs.
WALRUS	- Primary habitat is Eastern Arctic, but occasionally spotted off Newfoundland and Nova Scotia coasts. - Dark brown in colour. - Pups average 1.2 m, 120 lbs. - Adult males average 3 m, 2000 lbs.
WHITE-BEAKED DOLPHIN	- Up to 3 m in length. - Back and sides are dark grey to black. - Usually occur in herds of 6 - 8, but up to 1500 have been sighted.
HARBOUR PORPOISE	- Occurs close inshore in shallow coastal waters, bays, harbours, and river mouths. - Dark brown or grey on back and sides. - Occur in pairs or groups of 5 - 10.

Other possible animal targets may include tuna, averaging 3 - 5 m in length and 0.5 m across, as well as schools of salmon.

TABLE 2.14

MEDIUM MAN-MADE TARGETS (5 - 15 m)

OBJECTS	DIMENSIONS (m)				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	Freeboard	Draft	Length	Beam				Passive Devices	Active Devices	
1. INFLATABLE CRAFT										
a. Liferaft (Open)		1.64	5.6	2.23	Elongated	Fibreglass hull Neoprene	Orange	Reflective tape	Navigational lights Spotlght VHF radio & antenna	
b. Lifecraft (Open)	1.8		5.1	2.1	Elongated	Synthetic coated textile Aluminum deck	Orange	Retro-reflective tape	Whistle Flares Navigatn ights Strobe light EPIRB	
c. Rescue Craft	0.75		5.0	1.86	Elongated	Black neoprene	Black	Retro-reflective tape Mirrors	Exterior lighting Flares	9 man capacity.
2. RIGID CRAFT										
a. Service Craft		0.94	9.8	3.4	Elongated	Fibreglass	Black	Reflective tape	Navigational lights	

TABLE 2.14

MEDIUM MAN-MADE TARGETS (5 - 15 m) (Cont'd)

OBJECTS	DIMENSIONS (m)				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	Freeboard	Draft	Length	Beam				Passive Devices	Active Devices	
1. INFLATABLE CRAFT										
b. Service Craft (encls.)		1.21	16.0	5.18	Elongated	Fibreglass Rubber Aluminum alloy cover	Orange	Reflective tape	Optional radar VHF radio Searchlights	52 man capacity.
c. Lifecraft (Open)	4.0	2.58	12.6	5.6	Round Peaked in middle	Fire insulated steel cabin	Orange	Reflective tape	Searchlight Radio Observation light	125 man capacity.
d. Lifeboat (Open)	2.0		6.1	2.2	Elongated	Fibreglass reinforced polyester Polyurethane	Orange	Reflective tape	Searchlight EPIRB's	20 man capacity.
e. Lifeboat (Open)	1.7		12.26	3.94	Elongated	Fibreglass	Orange	Reflective tape	Searchlights EPIRB's Radio	40 man capacity.

TABLE 2.14

MEDIUM MAN-MADE TARGETS (5 - 15 m) (Cont'd)

OBJECTS	DIMENSIONS (m)				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	Freeboard	Draft	Length	Beam				Passive Devices	Active Devices	
f. Lifecraft (Encls.)	1.1		8.0	2.7	Round	Reinforced fibreglass Polyurethane foam backed by steel plate	International Orange	Reflective tape Signal mirrors	Flares Whistle VHF radio	50 man capacity.

TABLE 2.15

MEDIUM ANIMAL LIFE TARGETS
(5 m to 15 m)

TYPE	DESCRIPTION
HUMPBACK WHALE	- Common inshore and on Grand Banks during summer. - Body length of 16 m. - Black body, white undersides. - Travel in pairs or small groups.
MINKE WHALE	- Common in inshore Newfoundland waters during summer. Often approach boats. - 9 m in length. - Black body with white underbelly. - Travel alone, in pairs, or in trios.
SPERM WHALE	- Common in eastern Canadian waters. - 15 m in length. - Dark brown/grey in colour.
KILLER WHALE	- Common in inshore Newfoundland waters during spring and summer. - 9 m in length. - Back fin up to 1.8 m in height. - Travel in pods of 30 or more.
POTHEAD WHALE	- Common in Newfoundland waters in summer. - 6 m in length. - Black on back and sides, grey belly. - Travel in pods of 200 or more.

2.2.4 Large Targets (> 15 m)

Targets in this category are mainly large offshore fishing boats such as longliners, some types of pleasure craft, fishing net systems, oil slicks and a wide variety of vessels and boats engaged in commerce. The fishing net systems can be several hundred feet in length, supported by buoys and markers.

2.2.5 General Targets

Objects or occurrences that may be included as possible targets but do not have a specific size are:

(a) Parts of aircraft.
(b) Parts of vessels.
(c) Oil slicks.
(d) Nets.
(e) General debris.
(f) Signalling devices - dye release.
 - flares (8-60 sec., 30 000 candella).
 - rockets (40-60 sec., 380,000 candella).
 - lights.

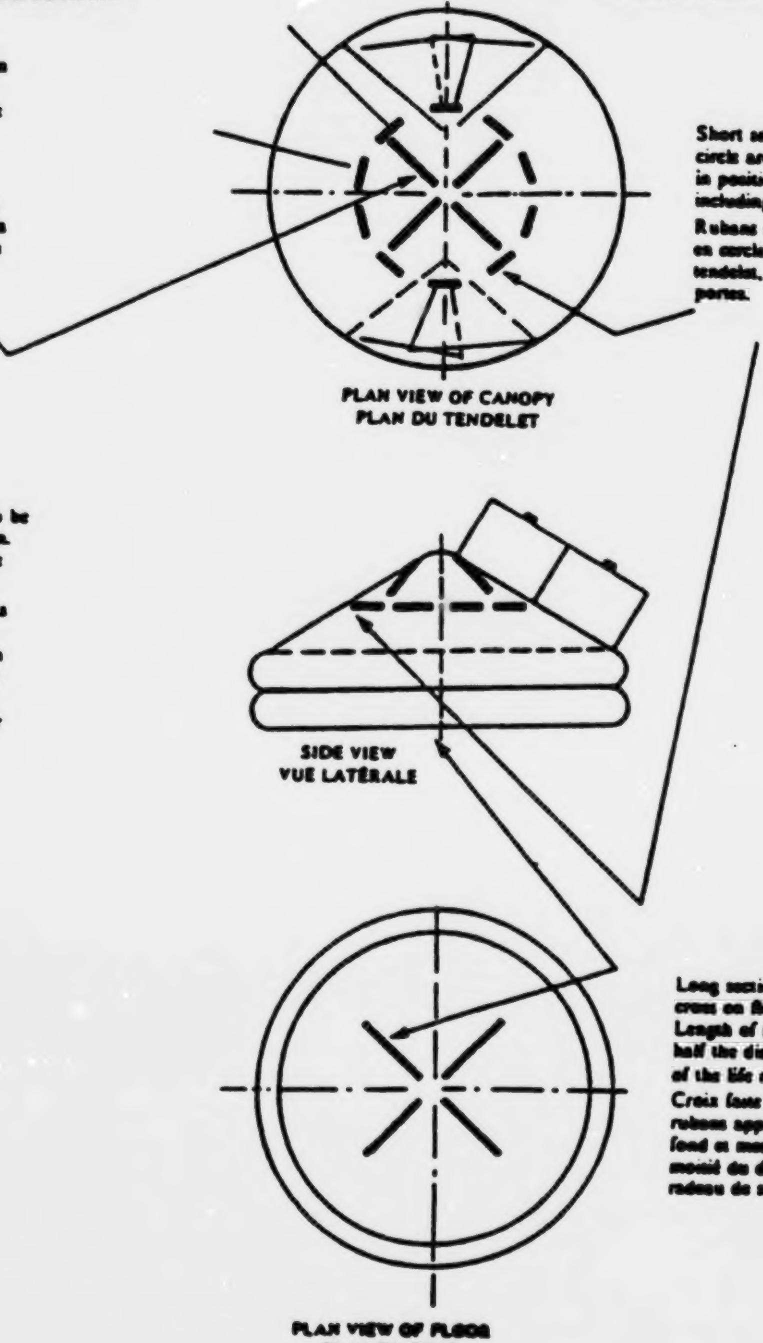
Other considerations are sea ice in concentrations of less than 1/10, iceberg targets of all sizes and categories, and reflective tape patterns. Tape patterns follow specific designs as shown in Figures 2.59 to 2.62.

2.3 Search and Rescue Concepts

Search area coverage involves the systematic search of suspected search and rescue areas to obtain the optimum probability of detecting a search target. In search and rescue operations there are many factors that influence detection capability; these are seldom identical in any two situations. The relative influence of the factors can, to some extent, be predicted or described. These factors can be reduced to four quantitative expressions which can be employed in search and rescue operations. The factors are as follows:

DIAGRAM I

DIAGRAMME I


PLAN VIEW OF CANOPY
PLAN DU TENDELET
SIDE VIEW
VUE LATÉRALE
PLAN VIEW OF FLOOR
PLAN DU FOND

Long sections to form cross on canopy. Length of strips to be half the diameter of the life raft.

Croix faite de longs rubans apposés sur le tendelet et mesurant la moitié du diamètre du radeau de sauvetage

Short sections to form circle around canopy in position shown including doorways.

Rubans courts disposés en cercle autour du tendelet, y compris les portes.

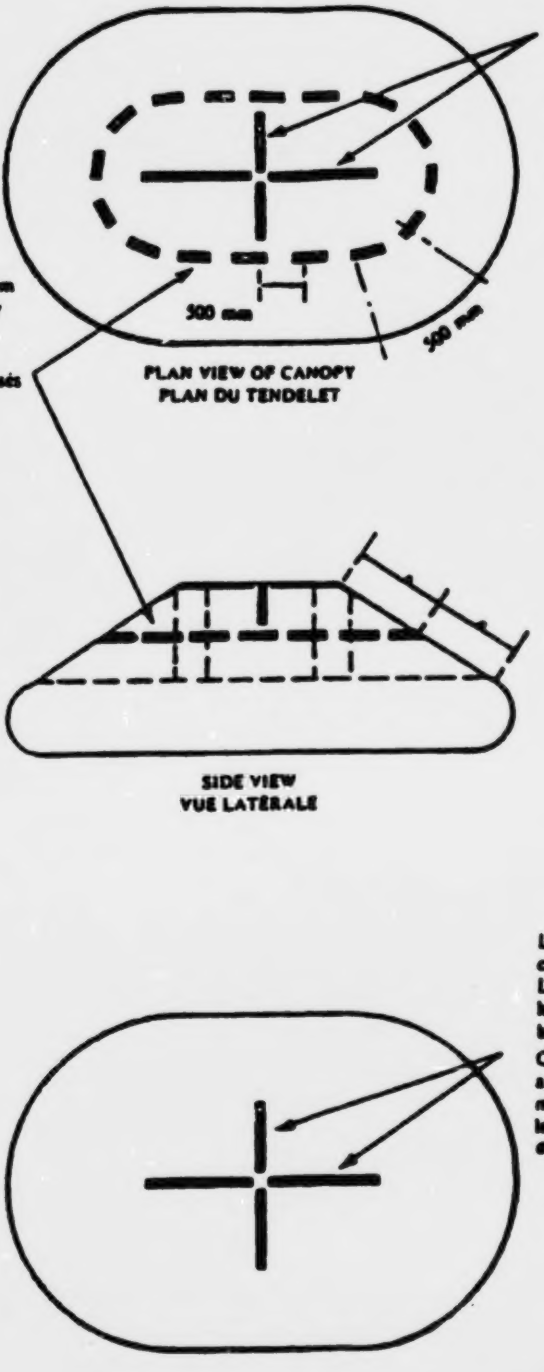
Note: Short sections to be 300 mm • 50 mm. Long strips to be 50 mm wide.

Note: Les rubans courts mesurent 300 mm • 50 mm Les rubans longs mesurent 50 mm de largeur

Long sections to form cross on floor. Length of sections to be half the diameter of the life raft.

Croix faite de longs rubans apposés sur le fond et mesurant la moitié du diamètre du radeau de sauvetage.

FIGURE 2.59 ARRA[redacted] OF RETRO-REFLECTIVE TAPE



Long sections to form cross on canopy.
Length of sections to be half the overall length and breadth respectively.

Croix faite de longs rubans apposés sur le tendelet et mesurant respectivement la moitié de la longueur et de la largeur hors-tout.

Short sections to form circle around canopy in position shown including doorways.

Rubans courts disposés en cercle autour du tendelet, y compris les portes

Note: Short sections to be 300 mm × 50 mm. Long sections to be 50 mm wide.

Note: Les rubans courts mesurent 300 mm × 50 mm Les rubans longs mesurent 50 mm de largeur

Long sections to form cross on floor.
Length of sections to be half the overall length and breadth respectively.

Croix faite de longs rubans apposés sur le fond et mesurant respectivement la moitié de la longueur et de la largeur hors-tout.

FIGURE 2.60 ARRANGEMENT OF RETRO-REFLECTIVE TAPE

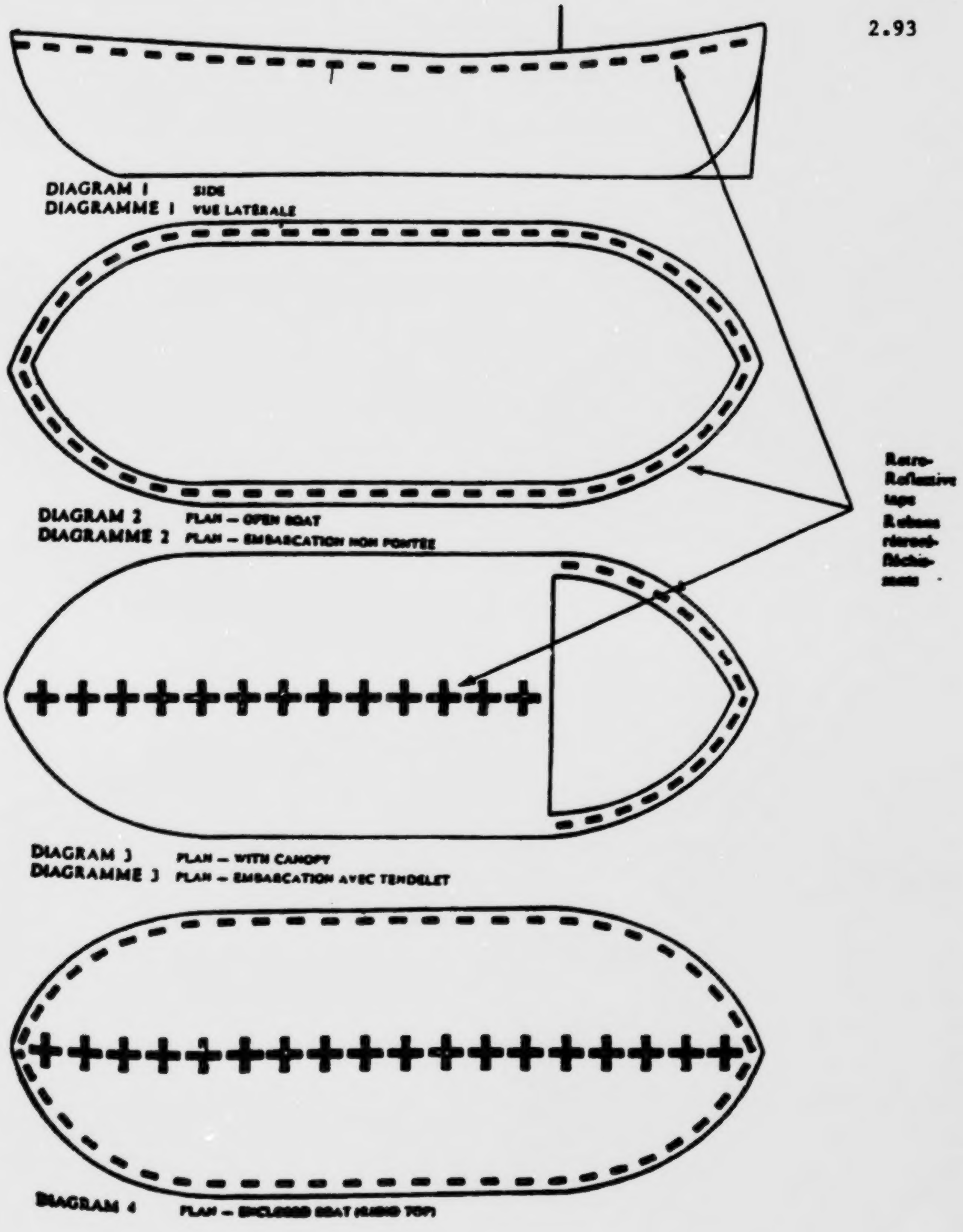


DIAGRAM 1 SIDE
DIAGRAMME 1 VUE LATÉRALE
DIAGRAM 2 PLAN — OPEN BOAT
DIAGRAMME 2 PLAN — EMBARCATION NON PONTÉE
DIAGRAM 3 PLAN — WITH CANOPY
DIAGRAMME 3 PLAN — EMBARCATION AVEC TENDELET
DIAGRAM 4 PLAN — ENCLOSED BOAT (RIGID TOP)
Retro-
Reflective
tape
Rubans
rétroré-
fléchis-
sants

FIGURE 2.61 RETRO-REFLECTIVE TAPE: SIDE, PLAN - OPEN BOAT, PLAN - WITH CANOPY, PLAN - ENCLOSED BOAT (rigid top)

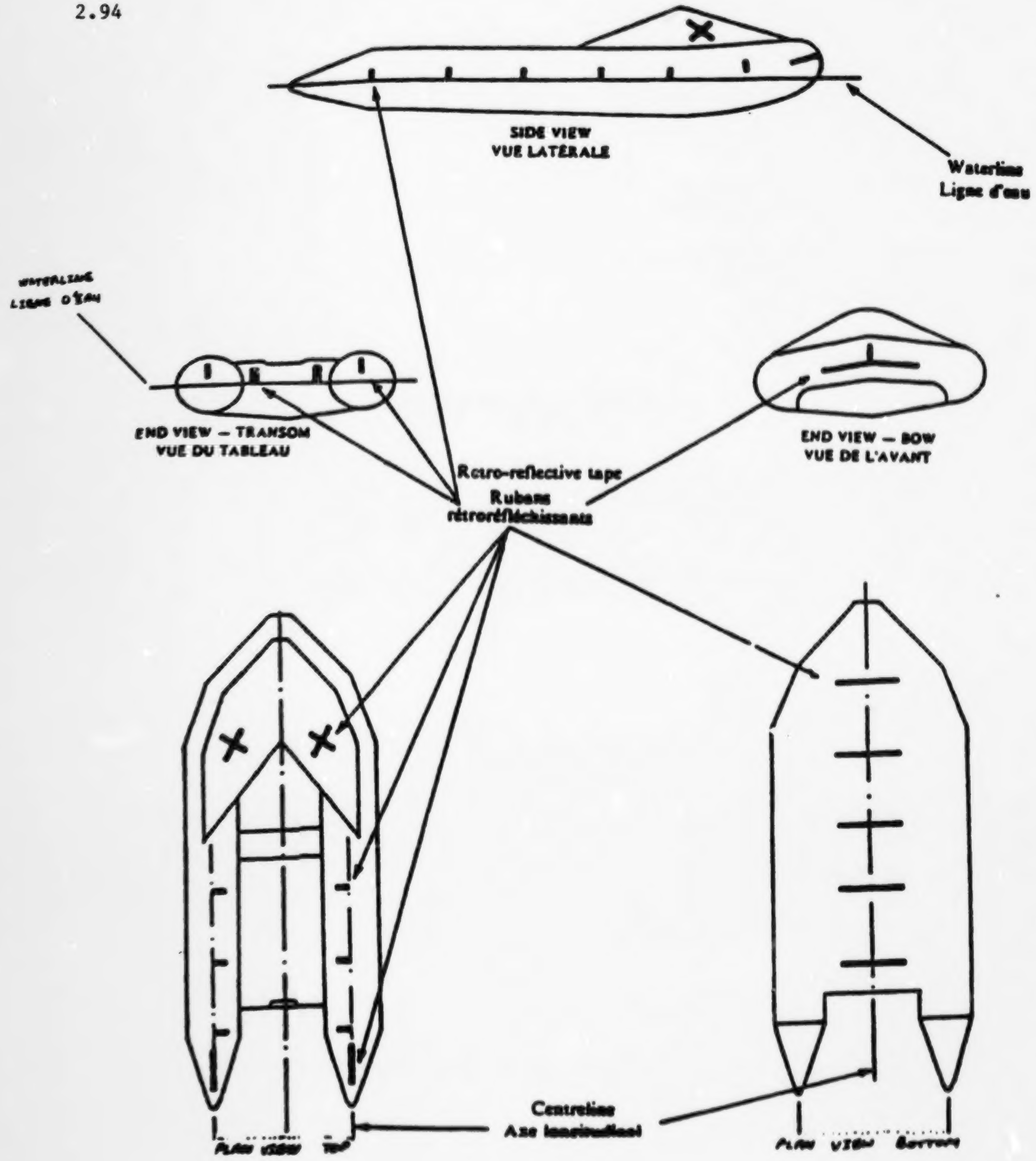

SIDE VIEW
VUE LATÉRALE
Waterline
Ligne d'eau
WATERLINE
LIGNE D'EAU
END VIEW — TRANSOM
VUE DU TABLEAU
END VIEW — BOW
VUE DE L'AVANT
Retro-reflective tape
Rubans rétroréfléchissants
Centreline
Axe longitudinal
PLAN VIEW TOP
PLAN VIEW BOTTOM

FIGURE 2.62 TYPICAL INFLATABLE BOAT ARRANGEMENT OF RETRO-REFLECTIVE TAPE

(a) Track Spacing (S).
(b) Probability of Detection (P).
(c) Sweep Width (W).
(d) Coverage Factor (C).

When considered in the broadest sense, descriptions of the above factors are as follows:

(a) S - a general measure of search effort.
(b) P - a measure of search results--either desired or attained.
(c) W - a measure of detection capability.
(d) C - a measure of search quality.

2.3.1 Track Spacing (S)

The track spacing is the distance between adjacent search tracks. Probability of detection can be increased by decreasing the track spacing, but this results in the requirement for more time to complete the search. If time is important, for example, the search can only be carried out during daylight hours, the higher probability of detection achieved by closer track spacing is maintained by searching smaller areas. Track spacing is optimal when the maximum expectaction of target detection in the available time is achieved. For aircraft search and rescue operations, track spacing is expressed in nautical miles. Figure 2.63 shows the concept for single or multiple aircraft.

2.3.2 Probability of Detection (P)

Probability of detection is used as a measure of search results. It can be expressed as the search results desired before a search commences, or it can express the results obtained by the search. P is expressed as a percentage in relation to search and rescue operations. A definite P exists for each search scan, whether it be by visual lookout or detection equipment. This is termed the 'instantaneous probability of detection'. It is not uniform across the scanned or swept area. In most instances, it is highest at short distances and decreases with distance from the observation platform. A typical P curve for instantaneous probability of detection vs. lateral range is shown in Figure 2.64. Detection range is measured from the position of

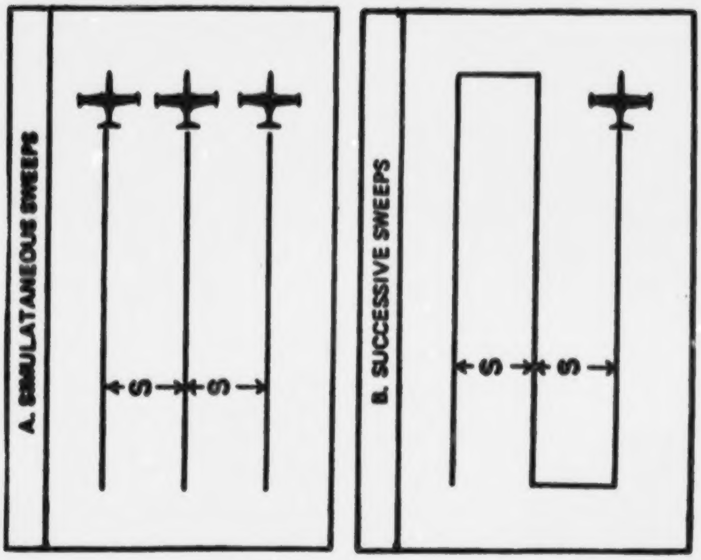

A. SIMULATANEOUS SWEEPS
S
S
B. SUCCESSIVE SWEEPS
S
S

FIGURE 2.63 GRAPHICAL PRESENTATION OF TRACK SPACING - S
(U.S.C.G. Publication CG308, July 1, 1973)

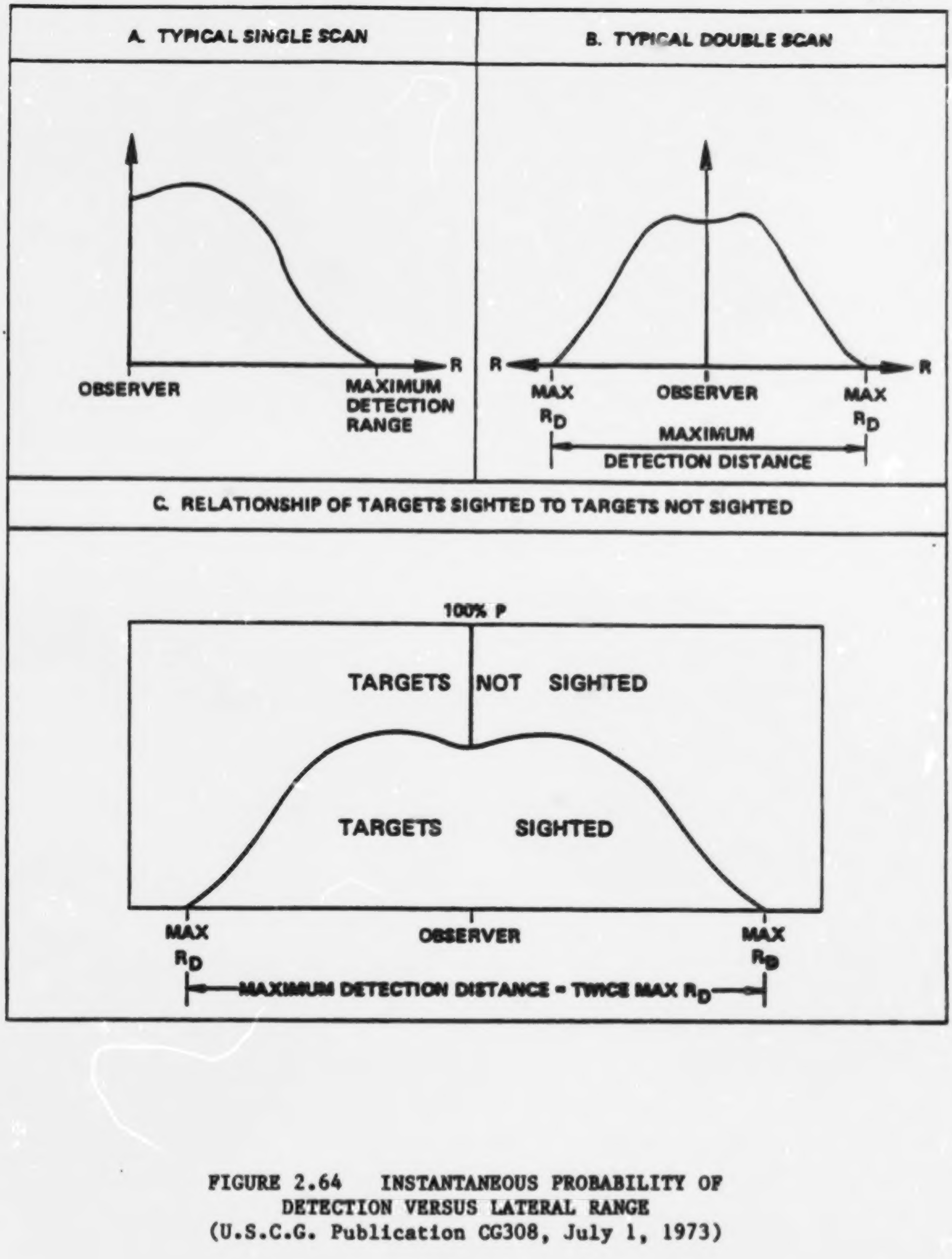

A. TYPICAL SINGLE SCAN
R
OBSERVER
MAXIMUM DETECTION RANGE
B. TYPICAL DOUBLE SCAN
R
R
MAX R_D
OBSERVER
MAX R_D
MAXIMUM DETECTION DISTANCE
C. RELATIONSHIP OF TARGETS SIGHTED TO TARGETS NOT SIGHTED
100% P
TARGETS NOT SIGHTED
TARGETS SIGHTED
MAX R_D
OBSERVER
MAX R_D
MAXIMUM DETECTION DISTANCE = TWICE MAX R_D

FIGURE 2.64 INSTANTANEOUS PROBABILITY OF DETECTION VERSUS LATERAL RANGE (U.S.C.G. Publication CG308, July 1, 1973)

the observer or detection instrument in the scan or look direction. It should be noted that there is a slight decrease in probability at very close range due to factors such as sea return during radar searches, purging over the target during sonar searches, and aircraft fuselage blocking in visual searches.

If a large number of identical targets were uniformly distributed along the lateral range of detection, most of the targets in the near range will be sighted, while targets in the far range will be sighted with less regularity. Beyond a certain range, called the maximum detection range, no targets will be sighted. By convention and experience, this is commonly graphed as a relationship between targets sighted and targets missed. To make this uniform, a concept termed 'sweep width' is used which reduces the detection capability for a given sweep to a single numerical value.

2.3.3 Sweep Width (W)

Sweep width is the mathematical expression of detection capability due to target characteristics, weather and other limitations. It is a numerical value obtained by reducing the maximum detection distance of any given sweep so that scattered targets which may be detected beyond the limits of W are equal in number to those that may be missed within W. This is shown in Figure 2.65. The shaded areas outside the sweep width where targets could be detected is equal to the shaded areas within the sweep width which contains the same number of non-detected targets. W is always less than the maximum detection distance and less than twice the maximum detection range. This concept is applicable for any type of search—visual, electronic, infrared, radar, and others.

2.3.4 Coverage Factor (C)

Coverage factor is a measure of the search effectiveness or its quality. It is normally used as an intermediate calculation when developing the probability of detection. It depends on the relationship between sweep width and track spacing. The mathematical expression is as follows:

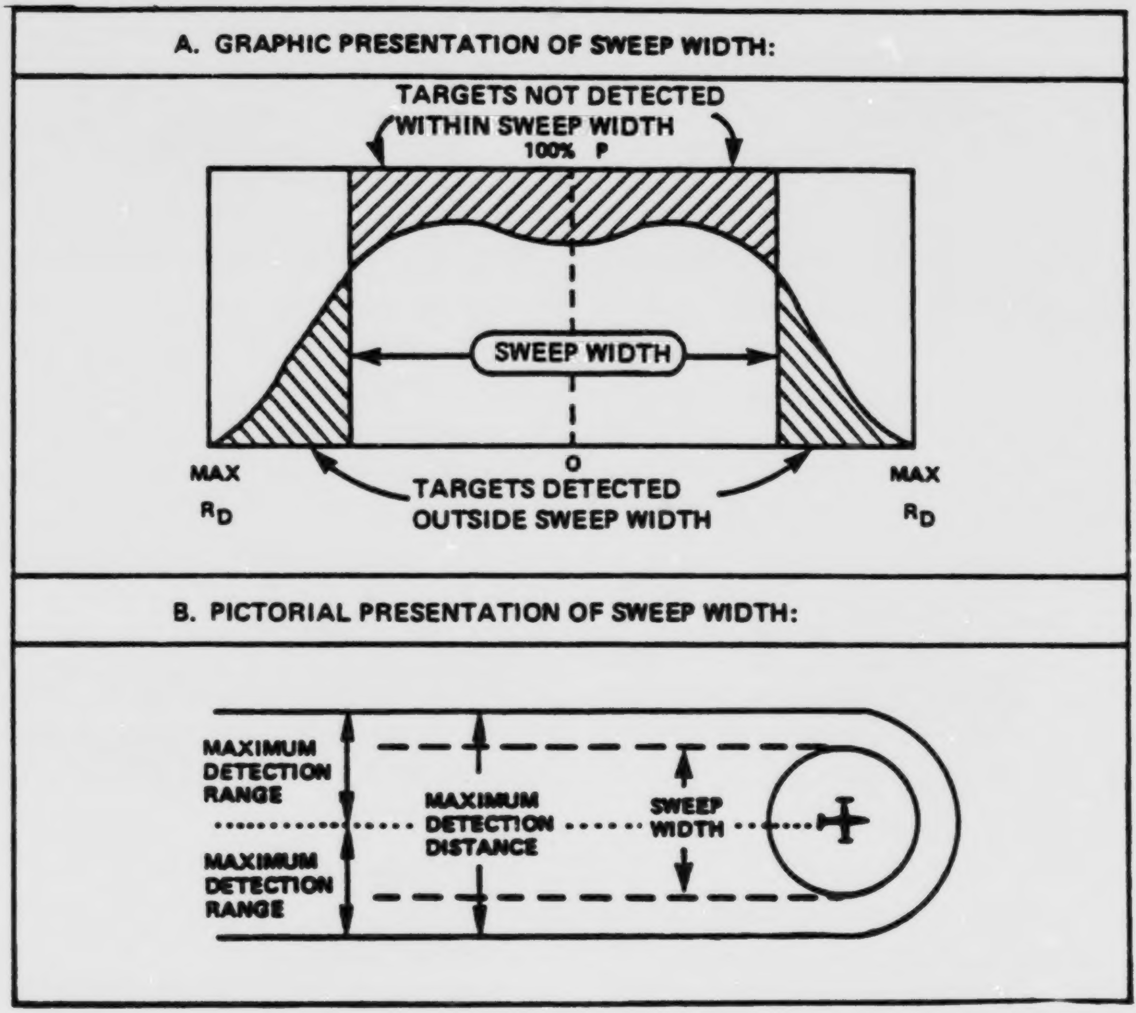

A. GRAPHIC PRESENTATION OF SWEEP WIDTH:
TARGETS NOT DETECTED WITHIN SWEEP WIDTH
100% P
SWEEP WIDTH
MAX R_D
0
TARGETS DETECTED OUTSIDE SWEEP WIDTH
MAX R_D
B. PICTORIAL PRESENTATION OF SWEEP WIDTH:
MAXIMUM DETECTION RANGE
MAXIMUM DETECTION DISTANCE
SWEEP WIDTH
MAXIMUM DETECTION RANGE

FIGURE 2.65 GRAPHIC PRESENTATION OF SWEEP WIDTH AND PICTORIAL PRESENTATION OF SWEEP WIDTH (U.S.C.G. Publication CG308, July 1, 1973)

$$\text{Conversion Factor} = \frac{\text{Sweep Width}}{\text{Track Spacing}}$$

or

$$C = \frac{W}{S}$$

Because W and S have the same dimensions, C is dimensionless. Comparisons of C can be seen in Figure 2.66. As C increases, more area is covered.

Coverage factor controls the probability of detection (Figure 2.67). This is accomplished by searching the area more than once. Nomographs have been developed to eliminate the need to calculate C (Figure 2.68). The nomograph allows the comparison of changes in S with P, when W is constant.

2.3.5 Visual Sweep Widths

Visual searches are the oldest and best-described forms of search. Other search methods have not been as extensively studied. All methods in the literature tend to be compared or associated with visual methodology.

Tables of sweep widths for visual search targets have been developed (Figure 2.69). Figure 2.69 gives uncorrected sweep widths (W_a) for rafts, boats and ships under daylight conditions. Correction factors are given for wind effects (f_w) on the ocean surface and for lighting conditions (f_l). Corrected sweep width from the figure is given as:

$$W = (W_u)(f_u)(f_l) .$$

The tables for W_a account for altitude of the platform and the meteorological visibility.

For targets smaller than life rafts, estimated sweep widths have been developed for daylight and darkness detection aids (Tables 2.16 and 2.17).

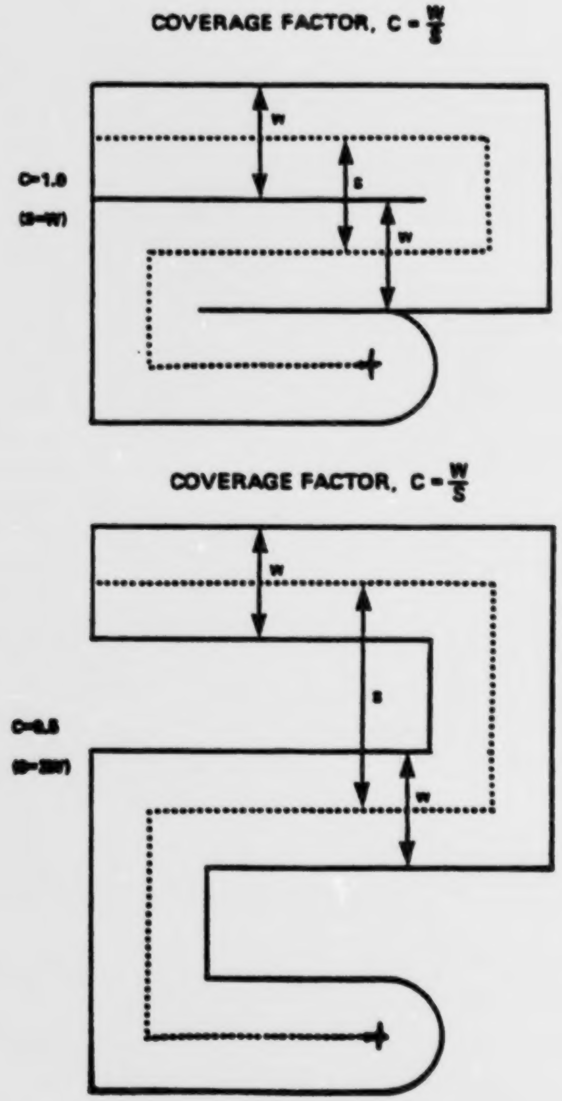

COVERAGE FACTOR, C = W/S
W
S
C=1.0
(S=W)
W
COVERAGE FACTOR, C = W/S
W
S
C=0.5
(S=2W)
W

FIGURE 2.66 COVERAGE FACTOR
(U.S.C.G. Publication CG308, July 1, 1973)

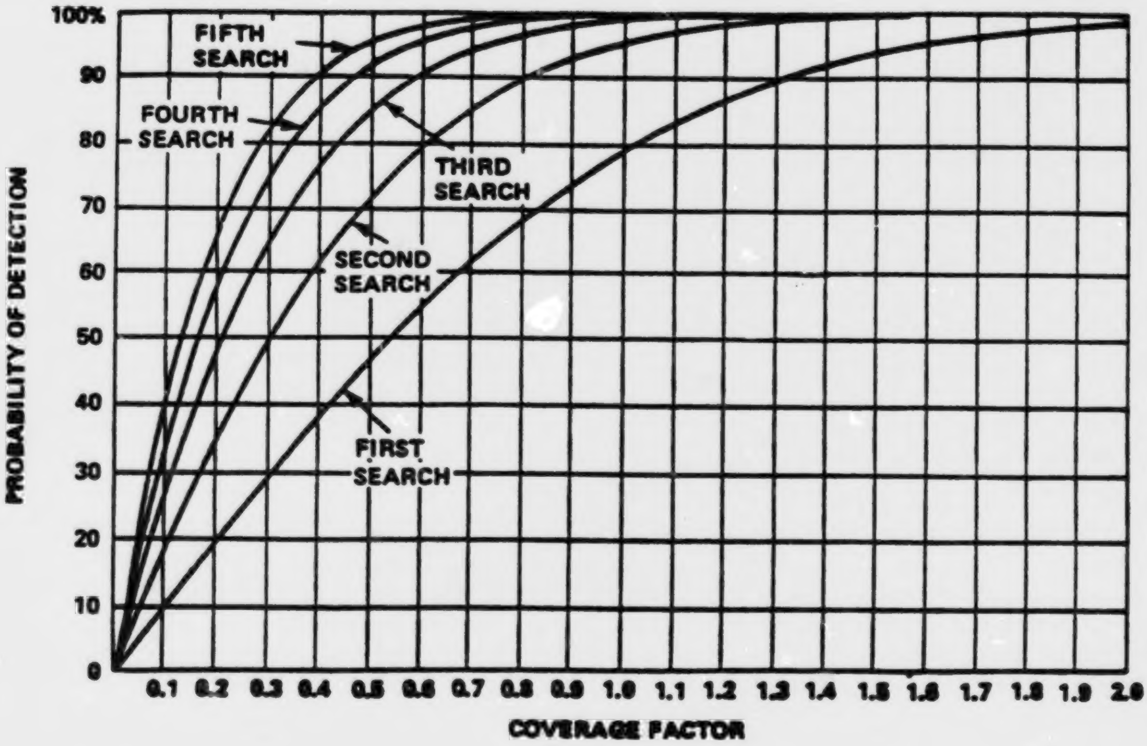


FIGURE 2.67 PROBABILITY OF DETECTION
(U.S.C.G. Publication CG-308, July 1, 1973)

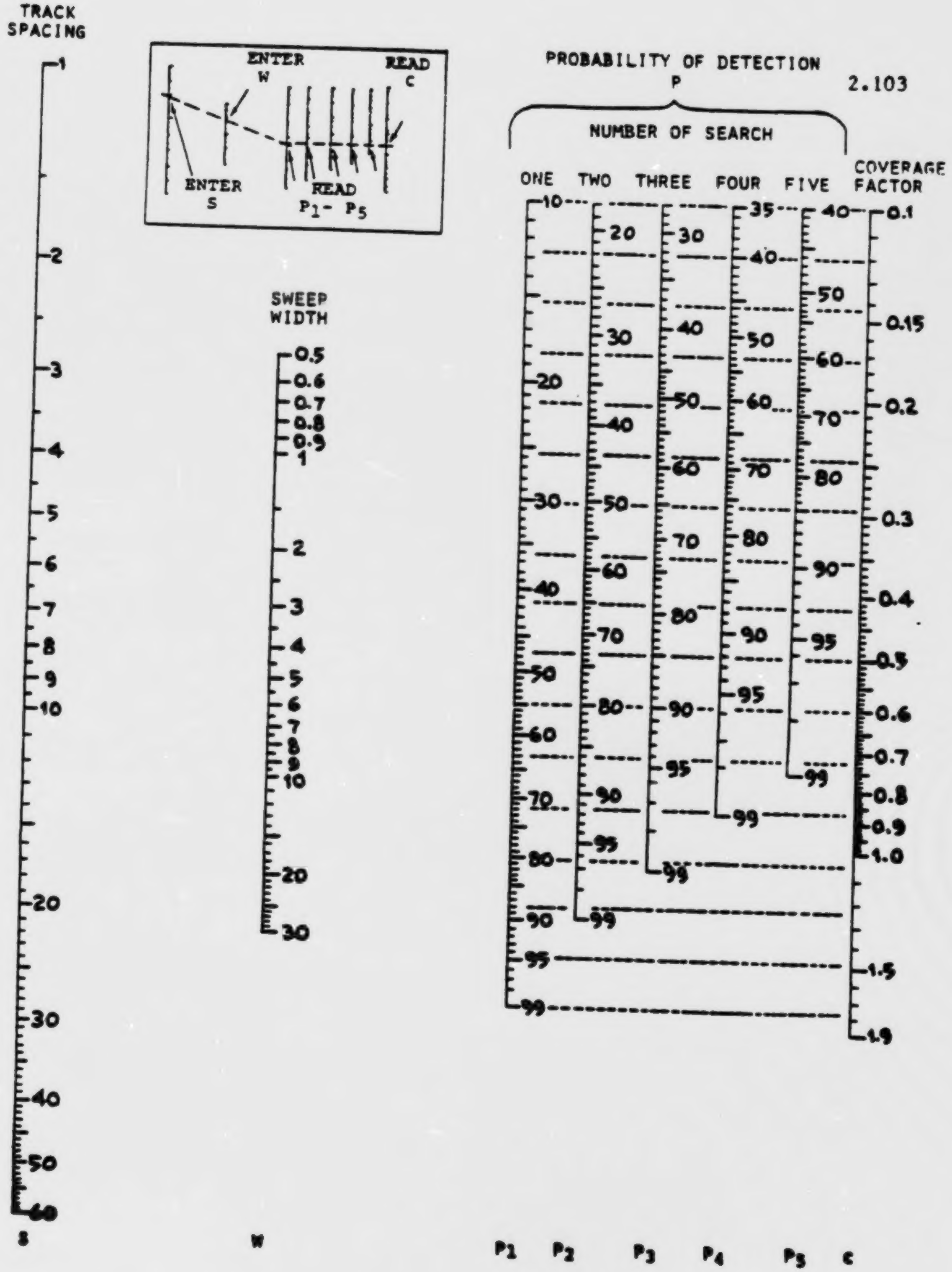


FIGURE 2.68 PROBABILITY OF DETECTION
(U.S.C.G. Publication CG-308, July 1, 1973)

Sweep Width (W) For Visual Search

(W Given In Nautical Miles)

		LIFECRAFT				BOATS (Less than 25')					BOATS (25'-65')					BOATS (65'-90')					SMALL SHIPS (100-1000 Gross Tons)					MEDIUM SHIPS (1000-10,000 Gross Tons)					LARGE SHIPS (Over 10,000 Gross Tons)				
ALTITUDE [illegible]		0	5	10	20	0	5	10	20	30	0	5	10	20	30	0	5	10	20	30	0	5	10	20	30	0	5	10	20	30	0	5	10	20	30
METEOROLOGICAL VISIBILITY (NAUTICAL MILES)	1	0.5	0.5	0.5	-	0.5	0.5	0.5	-	-	0.5	0.5	0.5	-	-	1.0	0.5	0.5	-	-	1.0	1.0	1.0	-	-	1.0	1.0	1.0	-	-	1.0	1.0	1.0	-	-
	3	1.0	1.2	1.2	1.0	2.5	2.4	2.3	1.8	0.4	3.5	3.0	2.7	1.8	0.4	3.9	3.4	3.2	1.8	0.4	4.2	3.8	3.2	1.8	0.4	4.6	4.0	3.3	1.8	0.4	4.7	4.0	3.3	1.8	0.4
	5	1.4	1.6	1.6	2.7	2.7	2.7	2.7	3.2	3.3	4.2	4.2	4.2	4.2	3.3	5.0	5.0	4.9	4.7	3.3	7.1	6.7	6.2	4.9	3.3	8.0	7.0	6.2	4.9	3.3	8.0	7.0	6.6	4.9	3.3
	10	1.8	1.8	2.1	3.6	3.9	4.0	4.2	4.5	5.0	6.5	6.2	6.2	6.2	6.5	8.0	8.0	7.9	7.7	7.2	11.0	10.0	9.8	8.6	7.2	11.0	10.6	10.2	9.0	7.2	11.0	10.6	10.2	9.1	7.2
	15	1.9	1.9	2.6	3.6	5.2	5.3	5.5	6.7	7.0	8.5	8.5	8.4	8.4	8.3	11.0	9.9	9.6	9.1	8.5	13.6	12.7	12.0	10.5	9.1	14.0	13.7	13.3	11.4	9.4	14.0	13.9	13.7	11.6	9.5
	20	2.0	2.1	2.8	3.6	5.3	5.6	6.2	6.8	7.1	8.6	8.8	9.0	9.1	8.9	12.0	11.0	10.6	10.0	9.3	15.0	14.3	13.5	11.9	10.4	15.0	15.0	15.1	13.0	10.9	15.0	15.0	15.6	13.3	11.1
	[illegible]	2.2	2.3	2.9	3.6	5.5	6.2	7.0	7.0	7.1	8.7	9.5	10.4	10.1	9.7	12.5	12.5	12.1	11.3	10.5	17.0	16.5	15.7	13.9	12.2	17.0	17.0	17.0	15.4	13.1	17.0	17.0	17.0	15.0	13.4
	[illegible]	2.2	2.4	2.9	3.6	5.6	6.3	7.1	7.1	7.2	8.9	10.0	11.0	10.8	10.3	13.0	13.0	13.2	12.2	11.3	17.0	17.0	17.2	15.3	13.5	17.0	17.0	18.0	17.1	14.7	17.0	17.0	18.0	17.5	15.0
	[illegible]	2.2	2.4	3.0	3.6	5.7	6.4	7.2	7.2	7.3	9.0	10.0	11.9	11.3	10.7	13.5	13.5	14.0	13.0	11.9	20.0	19.3	18.4	16.4	14.5	20.0	21.0	20.0	18.3	15.9	20.0	21.0	21.0	18.9	16.5

WHITECAP CORRECTION FACTOR (f_w)

WIND (kts)	0	10	15	20	25	30	40	50	60
Rafts	0.8	1.0	0.9	0.7	0.5	0.2	0.1	-	-
Boats	0.9	1.0	1.1	1.0	0.9	0.7	0.2	-	-
Ships	1.1	1.0	1.0	0.9	0.8	0.7	0.5	0.2	-
Dye Marker	0.9	1.0	1.0	0.9	0.6	0.4	0.2	-	-
Smoke	0.8	1.0	0.8	0.6	0.4	0.2	0.1	-	-

LIGHTING CORRECTION FACTOR (f_l)

PERCENT CLOUD COVER	0	10	20	30	40	50	60	70	80	90	100
CLOUD COVER FACTOR	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.8	0.7

FIGURE 2.69 SWEEP WIDTH (W) FOR VISUAL SEARCH
(U.S.C.G. Publication CG-308, July 1, 1973)

TABLE 2.16

DAYLIGHT DETECTION AIDS VISUAL SWEEP WIDTH

(U.S.C.G. Publication CG-308, July 1, 1973)

Device:	Estimated sweep width (miles)
Red/orange balloon	⅓
Red 2-star flare	⅓
Orange flight suit	⅓
Day/night flare	⅓
Red pengun flare	¾
Red reflective paulin	2
Tracer bullets	2
Green dye marker[1]	2
White parachute	5
Orange smoke[2]	5
Sun signal mirror	5

[1] Greatly reduced in heavy seas.

[2] Greatly reduced in high winds.

TABLE 2.17

DARKNESS DETECTION AIDS SWEEP WIDTHS

(U.S.C.G. Publication CG-308, July 1, 1973)

Device:	Estimated sweep width (miles)
Electric floating lantern	1
Hand flashlight	3
Tracer bullets	4
Red Very signals	8
Aircraft marine markers	8
Day/night flare	8
Strobe lifejacket light	5.5
Red pengun flare	10
Red 2-star flare	10

2.3.5.1 Search Target

Target detection is significantly related to size, shape, distance, colour contrast, brightness contrast, movement and duration of exposure. When detectability is considered, certain terms are used to help understand the situation. When a target is first detected but cannot be recognized, the distance between the observer and the target is called the 'awareness range'. When it can be recognized, the distance is known as the 'recognition range', and when identification is possible, the distance is the 'identification range'. Awareness range is the most important, because it defines the maximum detection range.

The amount of freeboard influences detection. A large target with a low freeboard can be more difficult to detect than a small target with a high freeboard. This is especially true with radar detection. Colour and its contrast with the surrounding background is important; the greater the contrast, the easier detection becomes. A small object with good target-to-background contrast can be easier to detect than a large target with poor contrast. Small targets have a limiting distance due to the physiological properties of colour vision that require direct viewing of the object. For example, yellow, red or orange have good contrast against a water background when no whitecaps exist, and blue is effective over forested areas. When whitecaps are present, red appears to exhibit the best contrast. A moving target in water will cause a wake which consequently improves the detection range. The effect of target plus water tends to enlarge the target. Movement in light seas is most easily detected, but with increasing sea state detection range drops off quickly. Small objects are more difficult to detect in high seas and search lines perpendicular to the swells will prolong the time that objects are visible to lookouts.

2.3.5.2 Meteorological Visibility

Meteorological visibility or range is the maximum range at which very large objects can be seen. As the meteorological visibility decreases, the sweep width will decrease accordingly. The detection range, except in the case of very large objects, is always less than the meteorological visibility. Haze, smoke, smog, fog, rain, sleet, snow, etc., are all obscurations to visbility that reduce the sweep width.

2.3.5.3 Sea Conditions

Calm waters are more easily searched than rough seas. Whitecaps, wind streaks, foam streaks, breaking seas, swell systems, spray and sun reflections all impose difficulties in visual searches over water. Targets may be hidden within these obscurations, and the more pronounced the conditions, the more difficult a target is to detect. These obscurations break the uniformity of the surface and are constantly changing. This movement makes it difficult to detect a target. Rough seas also impose difficulties on sensors such as radars.

2.3.5.4 Cloud Cover

Increases in cloud cover result in a lowering of the amount of ambient light available. This lowering of available light greatly reduces the sweep width. When cloud cover is scattered, the resultant cloud shadows make the surface mottled and non-uniform, making detection more difficult.

2.3.5.5 Search Altitude

Generally, the lower the altitude the better the chances of detection, but as the altitude decreases the targets appear in the field of view for shorter periods of time. This is especially true when search altitudes are less than 500'. Higher flying altitudes result in larger sweep widths. It is thus necessary to achieve a compromise based on the conditions at the time of search. The compromise also depends on the target being searched. A boat is more easily detected than a person in water, therefore a higher flight altitude is possible. For targets smaller than 30' in length, lower altitudes are much more efficient. Tests have shown that a visual observer's efficiency decreases rapidly in overland searches when altitudes increase from 200 to 2000'. After 2000', efficiency decreases only slightly. Similar results would be expected over water. The following rules of thumb are used to determine search altitude:

1) The smaller the target (or more difficult the target is to see), the lower the search altitude.
2) The lower the search altitude, the closer the track spacing.
3) The lower the search altitude, the slower the search speed.

4) 2000' appears to be a practical limit for visual search.
5) 500' to 1500' is a practical limit for over-water searches.
6) 800' is a typical altitude for boat-size (medium) targets.
7) 200' to 400' is a typical altitude for small targets such as people, one-man rafts, surfboards, etc.

2.3.5.6 Search Aircraft Speed

At low altitudes, the speed of the aircraft will affect the sweep width due to the angular velocity of targets moving through the observer's field of view. This will cause targets to blur at close range and decreases the exposure time to the observer. The higher the speed, the more pronounced these factors become.

2.3.5.7 Detection and Effectiveness

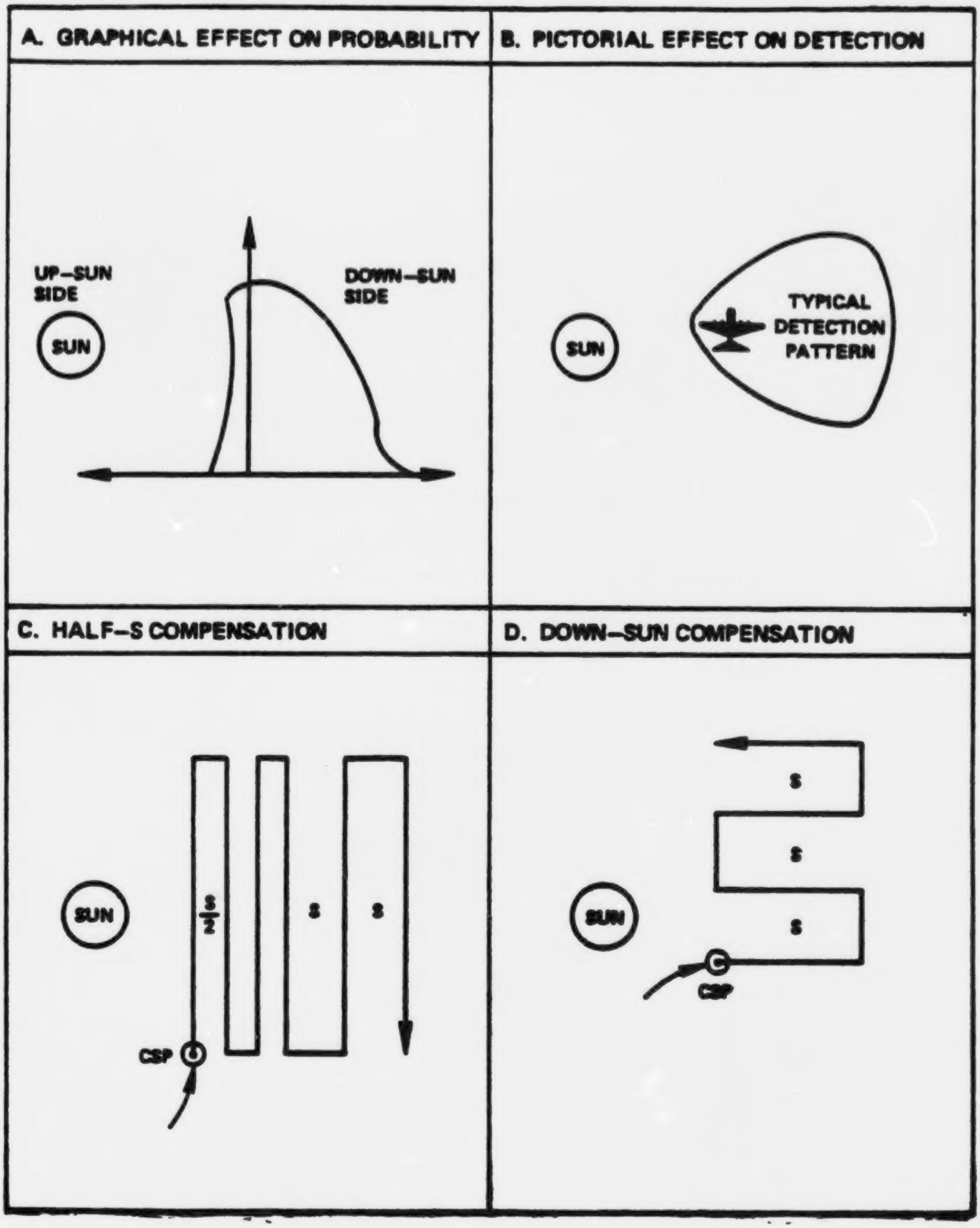
Detection aids are meant to make detection easier. Sea conditions, wind and visibility obscurations have some detrimental effect on aided detection, but aids have been shown to increase the probability of detection.

2.3.5.8 Position of Sun

The best time for target searching is when the sun elevation is high; this is true whether the sun is visible or not. Detection and detection range is greater down-sun (looking away from the sun) then when looking up-sun. This is due to sun reflection and haze glare. Reflected sunlight blots out smaller dark areas. Increased freeboard tends to negate the reflection influences. The veiling brightness of haze is greater up-sun than down-sun, and targets on the sea tend to lose their distinctive colours and become lost in the pattern of glossy light and shadow. Down-sun detection probability is higher because there is no glare, haze is more transparent, and colour objects contrast with the dark sea background. Up-sun problems are more accentuated when the sun elevation is low on the horizon. Figure 2.70 idealizes the effect of sun angle on detection probability and shows how to compensate.

2.3.5.9 Observer Effectiveness

Observer effectiveness is influenced by numbers, training, alertness, incentive, physical condition, dark adaptation, suitability



A. GRAPHICAL EFFECT ON PROBABILITY

B. PICTORIAL EFFECT ON DETECTION

C. HALF-S COMPENSATION

D. DOWN-SUN COMPENSATION

UP-SUN SIDE
SUN
DOWN-SUN SIDE
SUN
TYPICAL DETECTION PATTERN
SUN
S/2
S
S
CSP
SUN
S
S
S
CSP

FIGURE 2.70 EFFECT OF SUN ANGLE ON DETECTION PROBABILITY
(U.S.C.G. Publication CG-308, July 1, 1973)

and comfort, flight duration and search speed. Many studies have been, and are being, carried out to determine how to improve observer effectiveness. In Canada, these studies are for overland searches.

2.3.6 Electronic Sweep Widths

Sweep width tables for various types of electronic devices have not been developed to the same extent as visual sweep width tables. Current research, mainly by the U.S. Coast Guard, is attempting to remedy this situation and the new replacement manual for search and rescue is expected to reflect improvements in this area.

Under proper conditions, electronic searches are more efficient than visual searches. Radio and radar methods are the most effective, although other sensors are being tested. Larger track spacings are available with electronic search widths and result in a higher probability of detection for larger geographic areas in a shorter period of time.

2.3.6.1 EPIRB/ELT Sweep Width

When searching with radio devices, detection range data may be reported as maximum, mimimum or average ranges. The maximum detection range is the range at which the target was first detected which is the maximum of a series of radio ranges taken on the target. The minimum detection range is the range of first detection which is a minimum of a series of such ranges taken on the target. The average detection range is that range which is the average of a series of ranges at which a target is first detected. A series of guidelines is used to develop radio electronic sweep widths as follows:

(a) When minimum range of detection is known:

$$W = (1.7)(\text{Minimum Detection Range});$$

(b) When average detection range is known:

$$W = (1.5)(\text{Average Detection Range});$$

(c) When maximum detection range is known:

$$W = (1.0)(\text{Maximum Detection Range});$$

(d) When no detection range is known:

$$W = (0.5)(\text{Horizon Range}).$$

The horizon range is taken from tables and is dependent upon the height above ground. If the EPIRBs/ELTs are being searched with the VHF/UHF antenna located on top of the aircraft, W is reduced to 75% of its values. Range data concerning specific types of systems is available from equipment manufacturers.

2.3.6.2 Radar Sweep Widths

Radar sweep widths are determined in the same manner as EPIRB/ELT sweep widths. The dominating factors that influence radar range include sea state, platform stability, air temperature and density, atmospheric disturbances, radar frequency, power output, antenna rotation, receive sensitivity, target reflectivity, and others. The development of sweep widths is relatively new and still ongoing.

CHAPTER 3

SYSTEMS, PROBABILITY OF DETECTION AND STRATEGY EVALUATION

3.1 Visual Detection

For the purposes of this study, visual detection includes whatever can be detected by the human observer, as well as detection by sensors that have sensivity and operate in the visual and near visual portions of the electromagnetic spectrum (ultraviolet and infrared). The output from these systems is a pictorial format using television, photographic or visual hard copy. This output is a permanent record of what the human eye "can see", or almost see (the eye cannot see adjacent to the visible spectrum, but the information is similar).

3.1.1 Human Observer

3.1.1.1 Literature Review

The United States Coast Guard has carried out extensive studies and experiments concerned with human observation of small objects. The basic method has been outlined in Section 2.3 and is concerned with the development of numbers with specific meanings that combine various physical and environmental parameters. This method is operationally oriented and the resulting numbers have no meaning to the untrained. The method was developed in the 1940s and is still in use today. In the 1970s, a review was undertaken to assess the methodology in terms of new capabilities. The aim of the program is to determine the validity of the method, develop a new method, if necessary, and include electronic sensing in the methodology. The ultimate aim is to produce a new search and rescue manual to be used with the next generation of aircraft and sensing systems.

A report by Edwards et al (1978) summarizes the results of a visual detection performance experiment carried out in 1978. The program used both fixed-wing aircraft and helicopters. The aim of the study was to assess lateral range, wind speed, visibility, search unit type and search speed for fixed-wing aircraft and search duration for helicopters in terms of their effect on probability of detection. The results of the study showed that for the same environmental conditions, helicopter search performance was superior to that of fixed-wing aircraft. Specifically, wind speed and visibility were found to have a significant influence on sweep width for fixed-wing aircraft. As wind speed increased, sweep width decreased because of the presence of whitecaps. As visibility increased, sweep width increased. There was no difference in search capability between the two types of fixed-wing aircraft used. It was also discovered that the sweep width decreased as environmental conditions deteriorated. For helicopters, the most significant environmental parameters to effect sweep width were wind speed and visibility. The same observations were made for fixed-wing aircraft. The duration of search was also significant as sweep width decreased over time, with the noise and vibration environment of the helicopter being the possible reason. For both fixed-wing aircraft and helicopters, cloud cover, swell height, and sun angle were found to be insignificant but, the range of these conditions under which measurements were made was not wide enough to provide significant conclusions. Helicopters were found to outperform fixed-wing aircraft for the range of environmental conditions occurring during the test, mainly because faster aircraft speeds and higher flying altitudes reduced the sweep width compared to slower helicopters with lower flying altitudes. It was concluded that helicopters should conduct searches at the maximum speed that the environmental conditions at the time of the flight would permit, and that optimum search speed and altitude must be found for fixed-wing aircraft.

A 1980 study by Edwards et al (1980a) continued the development of detection probabilities for visual detection. This study was concerned with models; two theoretical curves and alternate models were tested. The study found that the alternatives provided better fit to the experimental data. For low coverage factors (C), the data was well represented by the inverse cube law model, and for $C > 0.8$, the empirical data fall between the inverse cube law and the random search curve. It was determined that the probability of detection (P) defined by the search and rescue manual overestimated P. Thus, it was recommended that changes be made to the operational methodology and the P should be determined using the empirically derived lateral range curves.

A second 1980 study (Edwards et al, 1980b) was concerned with the influence of sweep width, W, and found that certain variables had significance for life rafts and 16' open boats. The results are summarized in Table 3.1 for airborne platforms and show that under poor environmental conditions there was a rapid degradation in P vs. lateral range. When this is coupled with navigational inaccuracies, the assumption of uniform coverage of a search area is inappropriate. The report also made the observation that the collection of substantial data for poor environmental conditions is unlikely and that model developments to predict detection performance for marginal environmental conditions was necessary. These predictions could then be tested when the opportunities arise.

A 1981 study re-emphasized the results of the previous studies (Edwards et al, 1981). It was concerned with continued analysis of more data and reaches specific conclusions regarding lateral range curves and sweep width. The following conclusions were made in this report:

1) The type of search unit was significant in determining sweep width (i.e., helicopters outperformed fixed-wing aircraft).
2) Targets of similar size (i.e., 4- to 7-man life rafts and 16' open boats) can be grouped together in a detection model since their detectability is affected similarly by changes in environmental or search unit controllable parameters.
3) Extended visibility appeared to be limited as range increased. The experiment showed that there was no measureable increase in detection when meteorological visibility was more than 2.5 to 3 times the predicted detection range (50%).

TABLE 3.1

SIGNIFICANCE OF EXPLANATORY VARIABLES IN EXPLAINING VARIABILITY IN SWEEP WIDTH
(Edwards et al, 1980b)

SRU and Target Types		Significance of Explanatory Variables Evaluated (Yes/No)									
SRU TYPE	TARGET TYPE	SEARCH SPEED	VISIBILITY	WIND SPEED	SWELL HEIGHT	CLOUD COVER	ELEVATION OF SUN	TIME ON TASK	SRU TYPE	ALTITUDE (AIRCRAFT ONLY)	TARGET COLOR
Fixed wing aircraft	16' boats	Yes	Yes	Yes	No	Yes	No	No	-	*	Yes
Helicopters	16' boats	No	Yes	Yes	No	Yes	No	Yes	-	*	Yes
Fixed wing aircraft and helicopters	Life rafts	*	Yes	Yes	Yes	No	Yes	No	No	No	Yes

* For aircraft, search speed and altitude were fixed during life raft and 16-foot boat experiments, Therefore, the significance of these parameters is evaluated in terms of the respective targets. (Edwards et al, 1980(b))

4) The SAR Manual sweep widths for boats and life rafts are in conflict with the experimental data. The experiment showed no variability in aircraft sweep width for altitudes between 500' and 3000', while the manual states that there is an altitude variation.
5) For helicopters, the search speed should be the maximum possible under existing conditions. For fixed-wing craft, sweep width decreases with increase in search speed. It was felt that fixed-wing aircraft searches should have an air speed selected considering other parameters than sweep width, such as aircraft endurance, observer comfort, and controllability.
6) It was found that sweep width reduced as time on task increased. This is related to the human factors of observation over time.
7) With respect to wind speed and swell height, the search and rescue manual and the experimental results are contradictory. The experiment showed that there is a continual reduction in sweep width as wind speed and swell increases. The results show that wind speed and swell height should be considered together.
8) Elevation of the sun was not found to have a significant effect on probability of detection.
9) The results showed that the influence of cloud cover on sweep width appeared to be overstated in the sweep width tables.

The report covered three other factors that affected sweep width. The first was concerned with the shape of the lateral range curve. The search and rescue manual uses the inverse cube law, which overstates P at higher coverage factors. It was concluded that the P vs. lateral range curve shape as well as the sweep width must be known for operations. Secondly, the search and rescue manual assumes perfect navigation but the study showed navigational accuracies that were far from perfect and which had P lower and flatter than the theoretical P curve. Third, the location of the target was important. Borders of the search area are only covered once, while the central portions of the detection envelope are covered twice. The double coverage increases P for targets located in the central section of the detection envelope. The search and rescue manual assumes a uniform target distribution and is thus idealistic in its probability determination.

A study carried out in 1984 was concerned with techniques to estimate lateral range functions for visual detection (Weisinger and Wagner, 1984). Two physical models for visual detection were chosen. One model uses an experimentally derived description of the region which can be seen by a human eye at a given instant, and the second employs an empirically determined formula for the instantaneous probability of visual detection as a function of target area and contrast. Based on the evaluations, the first model, called the detection lobe model, was chosen. The remainder of the report was concerned with the development of an analytic approach to the construction of lateral range functions for visual detection. The visual sweep widths generated were consistent with empirical results and previous research, but the model development was not conclusive.

3.1.1.2 Sensor Description

In this case, the sensor is the human eye, which views that portion of the electromagnetic spectrum extending from blue to red. This spectral region is called the visible spectrum because it is seen by the human observer. The physiographic character of the eye, coupled with the condition of the human, affect observation.

Eye performance was studied by Blackwell et al (1982), in order to determine method of eye movement, and hence scanning pattern, of visual lookouts. It showed that the human observers were not employing the systematic scanning patterns outlined in USGC training manuals, even when they were aware of the prescribed procedures. A phenomenon called "eye lock" occurred, whereby eye movement would basically cease and the eye would stare at a fixed point. The resultant effect was that the movement of the observer vehicle dictated the eye scan path, resulting in a straight line observation path. It was also found that observers tended to search along obstructions or environmental configurations within their field of view. For example, observers would scan along window frames. The typical scan pattern would be a parallel sweep of the horizon and a vertical sweep of the window frame. If the observer was looking through several windows separated by frames, the observation pattern would be repeated. Observers were also noted to scan to their left. Thus, a right door observer would search laterally and toward the front of the aircraft, while a left door observer searched laterally and to the rear. Search strategies differed according to platform and position, but obstructions or environmental configurations were used as a guide for search patterns. This was determined to be an underlying tendency for all human observers. The excessive dependence on obstructions and environmental configuration suggests a need for artificial structuring of the observer's field of view. It was also determined that the observer had to be trained to search within the area of maximum detection range as determined by target type and environmental conditions. This would prevent the observer from scanning the horizon. It was also found that scanning should be concentrated near the search vehicle to provide better coverage of the search area because the near vehicle area on one search leg becomes the far range on the next leg of the search.

Another USCG study (Remondini et al, 1982) was concerned with human factors in search and rescue operations. It analyzes experience level, time on watch, amount of sleep and lookout position of the human observer. Certain physiological tests showed a marginal relationship between observers with high scores and higher detection frequencies. It was also shown that observers with previous experience had a higher detection frequency when in a helicopter, that hours on watch in a helicopter were independent of detection frequency, and that detection frequency was independent of the observers' prior sleep.

3.1.1.3 Probability of Detection

Edwards et al (1980b) provide detailed evaluation of the search and rescue probability-of-detection curves. Sweep width (W) is a mathematical measure of detection capability due to various factors, expressed as a numerical value. W is always less than the maximum detection distance and always less than twice the maximum detection range (Figure 3.1). The report defines sweep width as follows:

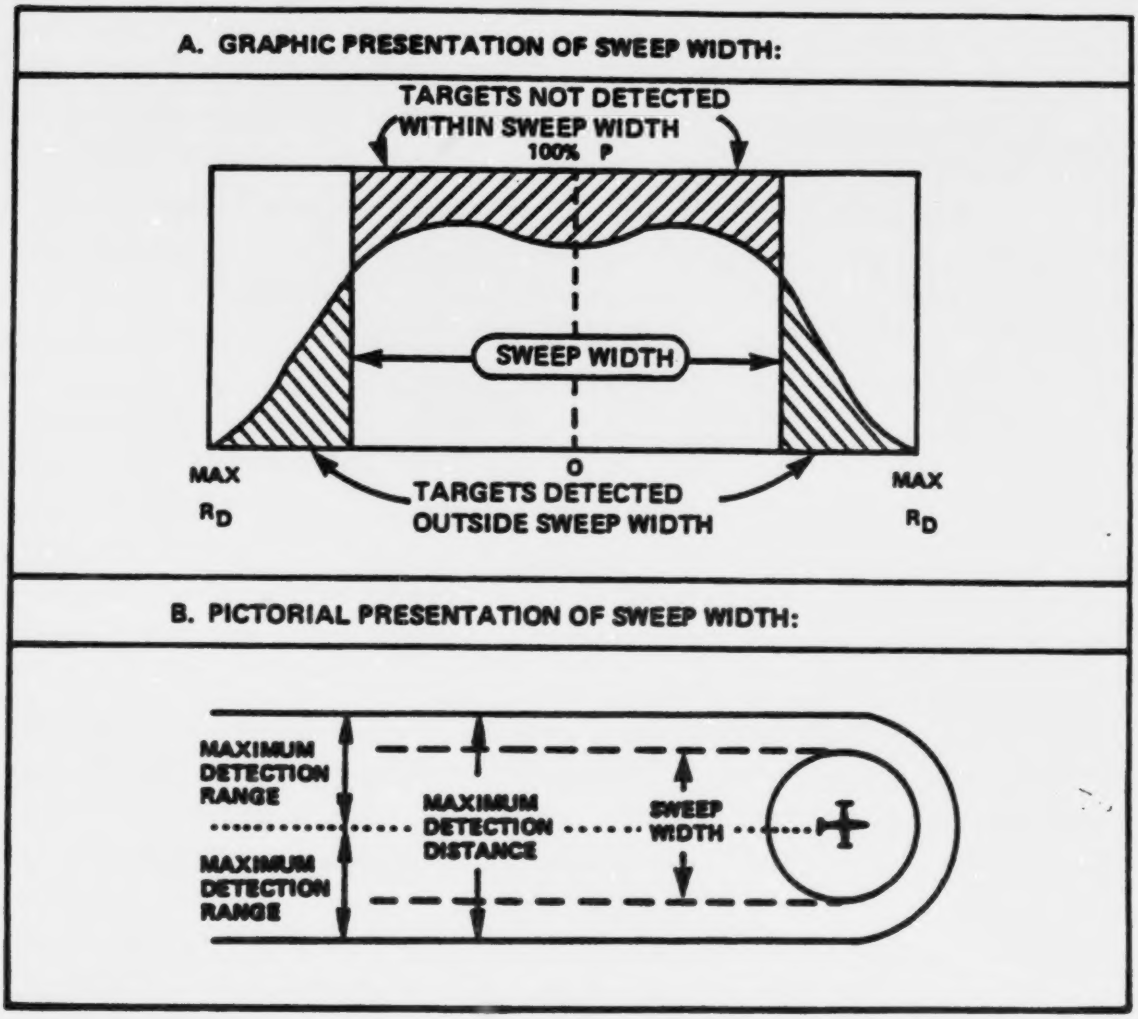

A. GRAPHIC PRESENTATION OF SWEEP WIDTH:
TARGETS NOT DETECTED WITHIN SWEEP WIDTH
100% P
SWEEP WIDTH
MAX R_D
0
TARGETS DETECTED OUTSIDE SWEEP WIDTH
MAX R_D
B. PICTORIAL PRESENTATION OF SWEEP WIDTH:
MAXIMUM DETECTION RANGE
MAXIMUM DETECTION DISTANCE
SWEEP WIDTH
MAXIMUM DETECTION RANGE

FIGURE 3.1 MAXIMUM DETECTION DISTANCE AND MAXIMUM DETECTION RANGE (U.S.C.G. Publication CG-308, July, 1973)

$$W = \int_{-\infty}^{\infty} P(x)\,dx$$

where x = lateral range or closest point of approach
of targets of opportunity (Figure 3.2)
P(x) = Probability of detection at lateral range x.

A typical P(x) curve is given in Figure 3.3. The concept used by the USCG is that W is a numerical value obtained by reducing the maximum lateral range of detection (R_D, Figure 3.3) of any given sweep so that scattered targets which may be detected beyond the limits of W are equal in number to those which may be missed within these limits, as depicted graphically in Figure 3.1. This means that W is defined when:

number of targets not detected within sweep width = number of targets detected outside sweep width

Details on this concept can be found in Koopman (1946).

W is dependent on a variety of environmental conditions, search and rescue unit (SRU) type, and target characteristics. Edwards et al (1980b) presents these variables in sweep width for visual detection (Table 3.2A and 3.2B).

Coverage factor is also explained for visual detection (Edwards et al, 1980b). To find the coverage factor, the track spacing (S) information is necessary. Track spacing is calculated using the information in Figure 3.4 at a desired or assigned probability of detection (POD). Thus, the coverage factor can be found from:

$$C = W/S .$$

This shows that search planning relies on the POD versus C model. The object of the USCG visual detection program was to validate this model.

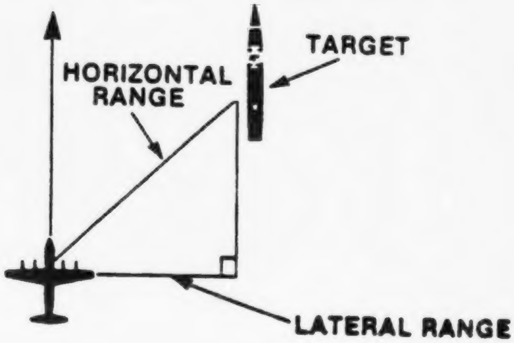

HORIZONTAL RANGE
TARGET
LATERAL RANGE

FIGURE 3.2 DEFINITION OF LATERAL RANGE
(Edwards et al, 1981)

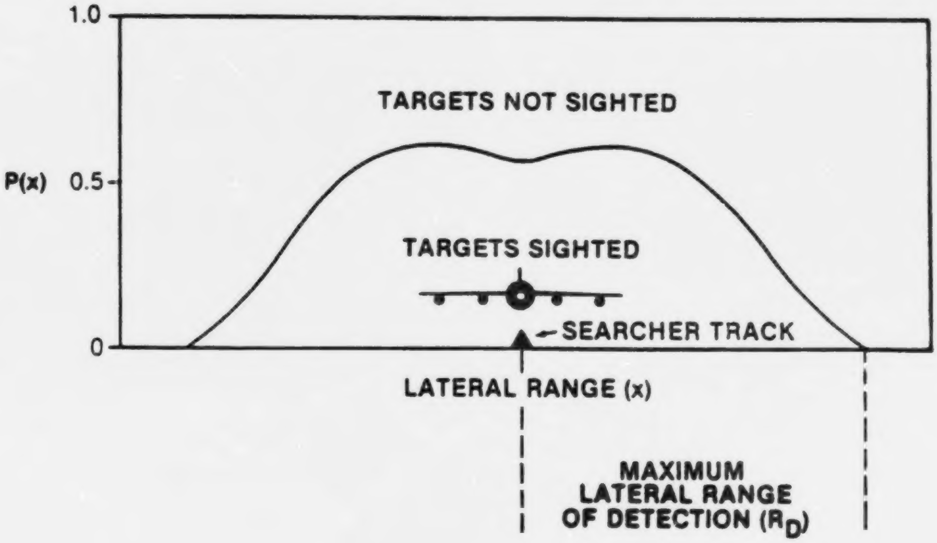


FIGURE 3.3 TYPICAL P(x) CURVE AS A FUNCTION OF LATERAL RANGE WHERE x IS THE LATERAL RANGE OF DETECTION OPPORTUNITIES (Edwards et al, 1981)

TABLE 3.2a

SWEEP WIDTH* CALCULATIONS FOR EXCELLENT CONDITIONS
(Edwards et al, 1980b)

SEARCH UNITS	TARGETS				
	LIFE RAFT			16-FOOT BOAT	
	ORANGE		BLACK	WHITE	BLUE
	with canopy	without canopy			
Cutters	6.1	5.7	5.2	5.7	4.9
Boats	4.6	4.1	3.6	4.7	3.7
Helicopters	3.7	3.2	2.7	5.6	5.0
Fixed wing aircraft	3.7	3.2	2.7	4.2	3.7

Excellent conditions: wind speed - 5 knots, swell height - 0 feet, cloud cover - 0 percent, visibility - 15 nm.

TABLE 3.2b

SWEEP WIDTH* CALCULATIONS FOR FAIR CONDITIONS
(Edwards et al, 1980b)

SEARCH UNITS	TARGETS				
	LIFE RAFT			16-FOOT BOAT	
	ORANGE		BLACK	WHITE	BLUE
	with canopy	without canopy			
Cutters	3.1	2.6	2.2	2.8	2.0
Boats	1.7	1.3	1.0	1.8	1.1
Helicopters	2.1	1.7	1.3	3.2	2.6
Fixed wing aircraft	2.1	1.7	1.3	2.3	2.0

Fair conditions: wind speed - 10 knots, swell height - 2 feet, cloud cover - 100 percent, visibility - 15 nm.

---

*Sweep width is given in nautical miles.

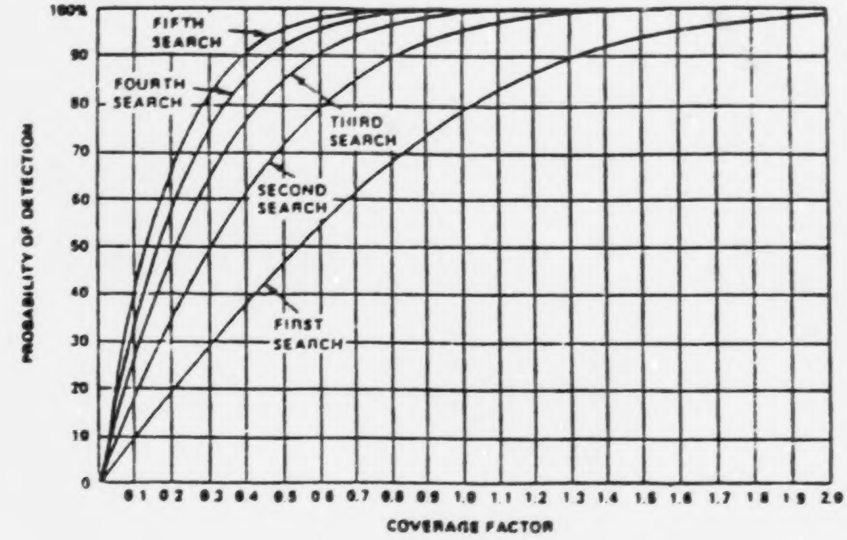


FIGURE 3.4 PROBABILITY OF DETECTION VERSUS COVERAGE FACTOR CURVE
(Edwards et al, 1980b)

The inverse cube law of detection states that the instantaneous glimpse probability of detection (δ) for a target can be seen by:

$$\delta = Kh/r^3$$

where K = a constant which depends on target area and intrinsic contrast with background,
h = altitude of searcher,
r = horizontal range to target (Figure 3.2).

From Koopman (1946), for continuous looking, the cumulative probability of detection (POD) as a function of time is:

$$POD = 1 - \exp(-\int_0^t \gamma dt)$$

and that for a parallel sweep search, the cumulative POD is:

$$POD = \frac{2}{\sqrt{\pi}} \int_0^z \exp(-z^2)dz = erf(z)$$

where

$$z = \frac{\sqrt{\pi}}{2} \cdot \frac{W}{S}$$

This curve forms the basis of Figure 3.4. To use the POD equation, the following assumptions are made:

(a) The target is located randomly within the search area and remains in the area for the entire search.
(b) The area is covered by equally-spaced, parallel search tracks.
(c) Constant environmental conditions prevail over the duration of the search (i.e., constant W for any SRU or target type).

(d) A number of 'passes' are made on both sides of the target by the searcher.

(e) The instantaneous probability of detecting (δ) the target is dependent on the surface area and intrinsic contrast of the target.

(f) The altitude of the searcher is small compared with the range to the target.

The uniform random search model represents the case where the least information is known about the target and no systematic search plan is used. It can be shown that for this case (Naval Operations Analysis, 1968),

$$POD = 1 - e^{-W/S} = 1 - e^{-c}$$

Figure 3.5 shows the relationship between the two models. The inverse cube law provides higher prediction of POD than the random search model for the same coverage factor, because a systematic means of search is assumed.

Edwards et al (1980b) provides a summary of detection opportunities. There were 966 target opportunities in 322 searches (Table 3.3). In Table 3.3, search time is defined as the cumulative hours each search and rescue unit spent searching. The number of searches includes the total number of searches conducted by each search and rescue unit type. This report is only concerned with airborne searches, therefore the number of target detection opportunities increases to 461 target opportunities in 186 searches. Table 3.4 gives the range of environmental conditions encountered during the various experiments. It was not possible to encounter the more extreme, poorer conditions during the experiment, as experiments were carried out during actual search and rescue missions and not during special programs. Poorer conditions would be: visibility less than 5 nm, wind speed greater than 20 kts and swell height greater than 4'.

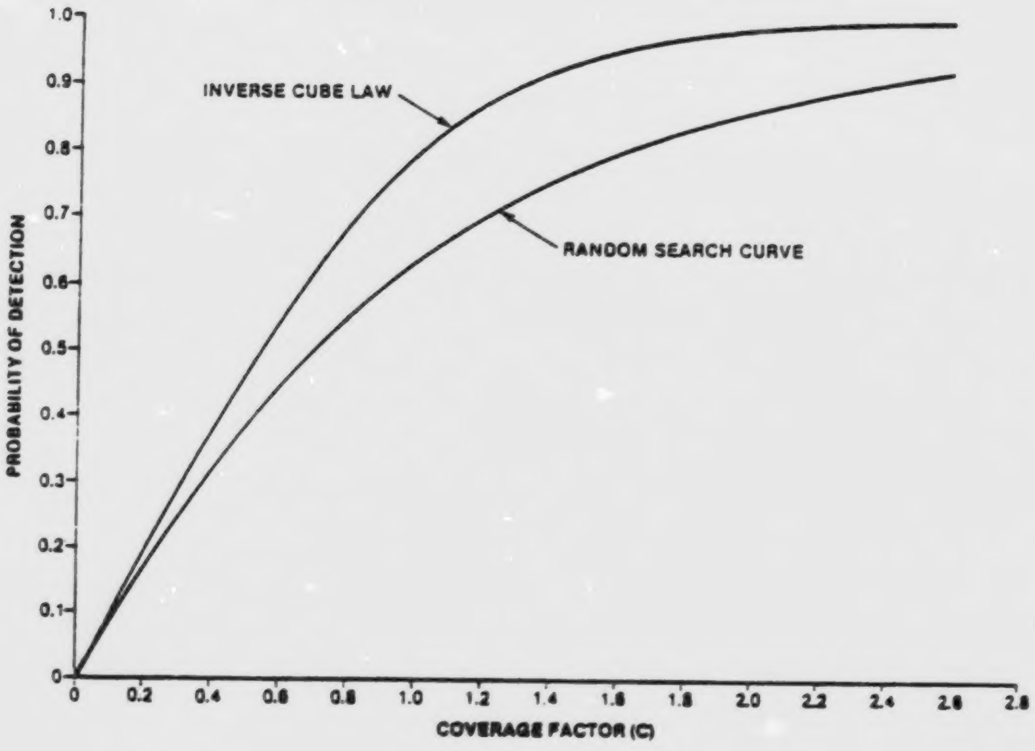


FIGURE 3.5 COMPARISON OF INVERSE CUBE LAW AND UNIFORM RANDOM SEARCH MODELS
(Edwards et al, 1980b)

TABLE 3.3

SUMMARY OF SRU RESOURCES

(Edwards et al, 1980b)

SRU Type	Target Type	Total Search Time (hr)	No. of Searches	Total No. of Detection Opportunities.
Fixed wing aircraft	Boats	37.0	41	114
Fixed wing aircraft	Rafts	30.4	46	105
Helicopters	Boats	44.6	56	145
Helicopters	Rafts	28.5	43	97

TABLE 3.4

RANGE OF EXPERIMENT ENVIRONMENTAL CONDITIONS
(Edwards et al, 1980b)

SRU Type	Target Type	Range of Environmental Conditions*		
		Visibility (nm)	Wind Speed (knots)	Swell Height (ft)
Surface craft	Boats	3-20(91)	0-22(98)	0-4(93)
	Life rafts	3-18(91)	0-17(93)	0-2(77)
Aircraft	Boats	5-15(83)	0-20(97)	0-3(87)
	Life rafts	5-15(83)	0-20(97)	0-3(87)

*Numbers in parentheses indicate the percentage of FY 1979 SAR cases involving 16- to 25-foot targets that are represented by the range of environmental conditions experienced during the experiments.

In the USCG analysis of the data, target validity was determined by the following criteria:

(a) The target must have been located within the boundaries of the search area.

(b) The target must have remained in the search area for the full duration of the search.

Therefore, the POD could be determined from:

$$\text{POD} = \frac{\text{number of valid detections}}{\text{number of valid opportunities}}$$

Target distribution was determined using a normalized coordinate system that could be used to compare target locations in a consistent manner over all searches. The data was sorted by search and rescue unit type, target type and environmental conditions. This resulted in several separate data bases. Using S and W for each case, the coverage factor was calculated. A preliminary POD versus C curve was produced for the separate data bases using a method given by Richardson et al (1974) to produce a data set suitable for curve fitting. Several fitting functions were evaluated.

Figure 3.6, which is a plot of POD versus C for the inverse cube law model, the random search curve and two suitable fitting functions, resulted from the analysis by Edwards et al (1980b). The fitting functions were as follows:

$$1)\quad \text{POD} = \text{Tan h}\,(0.943\,C).$$

$$2)\quad \text{POD} = 1 - e^{-1.30C}$$

The number of detections versus opportunities is given in brackets. This data shows that for $C < 0.8$, the inverse cube law holds, but for $C > 0.8$, the data follow some other function which is closer to the two fitting functions. The report assessed goodness of fit, compared data by search-and-rescue type, carried out best fit for search-and-rescue type, compared data by experiment, and assessed the range of environmental conditions. The report provided the following conclusions:

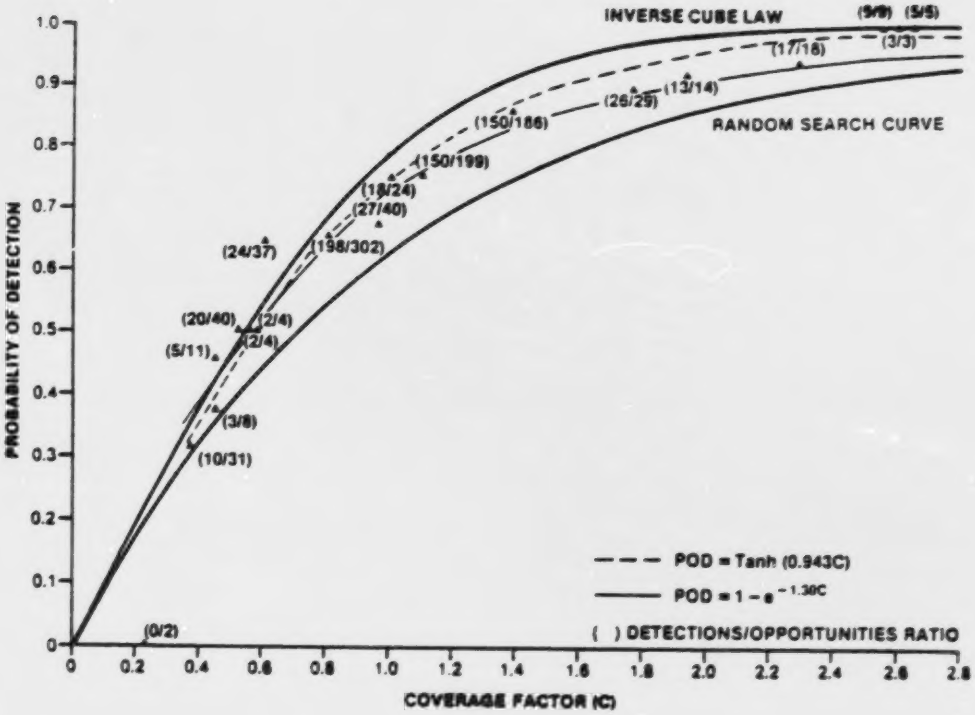


FIGURE 3.6 COMPARISON OF EXPERIMENTAL RESULTS TO POD MODELS (all SRUs) (Edwards et al, 1980b)

1) There is a clear need to revise the search and rescue manual POD versus C model.
2) The standard method of determining POD should use empirically-derived lateral range curves by "driving" them through the search area to determine expected values of POD directly.

Further studies are reported in Edwards et al (1981) and provide analysis from seven visual detection experiments. A total of 4916 detection opportunities were reported. Table 3.5 gives a summary of search and rescue unit type, target type, total search time, total mission time and detection opportunities; Table 3.6 gives the range of environmental conditions. The total number of detection opportunities for airborne platforms for all target types was 2496. The primary objectives of the study were to determine the significance of the independent variables and to develop sweep width estimates for each search and rescue unit class. Because W is a single numerical representation of a complex lateral range/probability of detection relationship, the key task of the study was to develop P(x) versus lateral range curves that would accurately represent the data. A stimulus-response (S-R) curve generally represents the data (Figure 3.7). A linear logistic model called LOGODDS was selected as the best candidate to fit the S-R data. The equation used by LOGODDS for target detection probability is:

$$R = 1/(1 + e^{-\lambda})$$

where R is the probability of interest and:

$x = a_0 + a_1x_1 + a_2x_2 = \dots$

a_i = constants determined by the computer program

x_i = independent variable values.

The interdependent variables can be continuous (eg. range, search speed, wind speed) or binary (eg. day/night, black/orange, cutter/boat).

TABLE 3.5

SUMMARY OF SRU RESOURCES
(Edwards et al, 1981)

SRU TYPE	TARGET TYPE	TOTAL SEARCH TIME (hr)	TOTAL MISSION TIME (hr)	TOTAL NUMBER OF DETECTION OPPORTUNITIES
Boats	16-foot boats	104.9	189.9	275
	41-foot boats	17.6	37.1	40
	Life rafts	74.4	133.5	260
	PIWs	75.7	131.5	341
Cutters	16-foot boats	176.8	418.1	432
	41-foot boats	24.9	54.1	45
	Life rafts	133.7	308.8	509
	PIWs	71.6	140.1	518
Helicopters	16-foot boats	55.0	227.5	415
	41-foot boats	11.7	78.2	34
	Life rafts	44.0	220.4	279
	PIWs	31.3	173.0	414
Fixed-wing aircraft	16-foot boats	37.0	173.2	405
	41-foot boats	9.2	30.4	44
	Life rafts	39.8	285.9	253
	PIWs	40.2	191.6	652

TABLE 3.6

RANGE OF EXPERIMENT ENVIRONMENTAL CONDITIONS
(Edwards et al, 1981)

SRU TYPE	TARGET TYPE	RANGE OF ENVIRONMENTAL CONDITIONS*		
		VISIBILITY (nm)	WIND SPEED (knots)	SWELL HEIGHT (ft)
Surface craft	16-foot boats	3-20(85)	0-25(97)	0-5(92)
	Life rafts	1-18(93)	0-19(87)	0-3(78)
	PIWs	2-20(90)	0-21(94)	0-5(92)
	41-foot boats	10-15	4-17	1-3
Aircraft	16-foot boats	3-20(91)	0-20(90)	0-3(66)
	Life rafts	4-15(86)	0-30(97)	0-4(76)
	PIWs	4-15(86)	0-22(90)	0-3(66)
	41-foot boats	12-15	10-18	2-3

*Numbers in parentheses indicate the percentage of FY 1980 searches that are represented by the range of environmental conditions experienced during the experiments. The 41-foot boat data base was too small to indicate percentages.

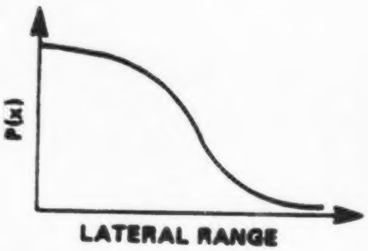


FIGURE 3.7 S-R CURVE REPRESENTING IDEALIZED P(x) VERSUS LATERAL RANGE (Edwards et al, 1981)

For aircraft detection of 16' boats and life rafts, there were 694 detection opportunities for helicopters and 658 detection opportunities for fixed-wing aircraft. Those values found not to have a significant influence on P(x) were: elevation of the sun, aircraft altitude, geographic location of the search area, and target location within the search area. The computed and actual P(x) versus lateral range curve for the case identified is given in Figure 3.8. In analyzing the data, the USCG found that helicopter performed better than fixed-wing aircraft, and it was postulated that this difference resulted from the differences in search speeds. It was found that search speed influenced the performance of fixed-wing aircraft but not helicopters. Figure 3.9 shows the predicted reduction in fixed-wing aircraft sweep width as search speed is increased, and Table 3.7 shows that the reduction appears primarily at longer lateral ranges. The report also presents data on W for various target types and colours.

For aircraft detection of PIWs, there were 652 detection opportunities for fixed-wing aircraft and 414 detection opportunities for helicopters. Figure 3.10 gives sample predicted and actual P(x) versus lateral range for a specific baseline case. Table 3.8 shows the influence on P(x) of changes in significant parameters. The study found that search and rescue unit type, visibility, cloud cover, aircraft altitude, elevation of the sun, geographical location and target location within the search area had no significant influence on P(x). Figure 3.11 shows the effect of aircraft altitude changes. This figure shows that the cumulative probability of detection (CDP) is less than 0.1 beyond 0.4 nautical miles for all altitudes in the detection of PIWs; for higher altitudes and ranges inside 0.1 nautical miles, the CDP is significantly lower and CDP doesn't reach 1.0, even at zero range. Table 3.9 shows W for PIWs in specific environmental conditions.

In addition to the conclusions outlined in Section 3.1.1.1, the study made general conclusions concerning the lateral range curve shape, navigational accuracy and target location. First, to accurately predict POD, the P(x) versus lateral range curve, as well as the sweep

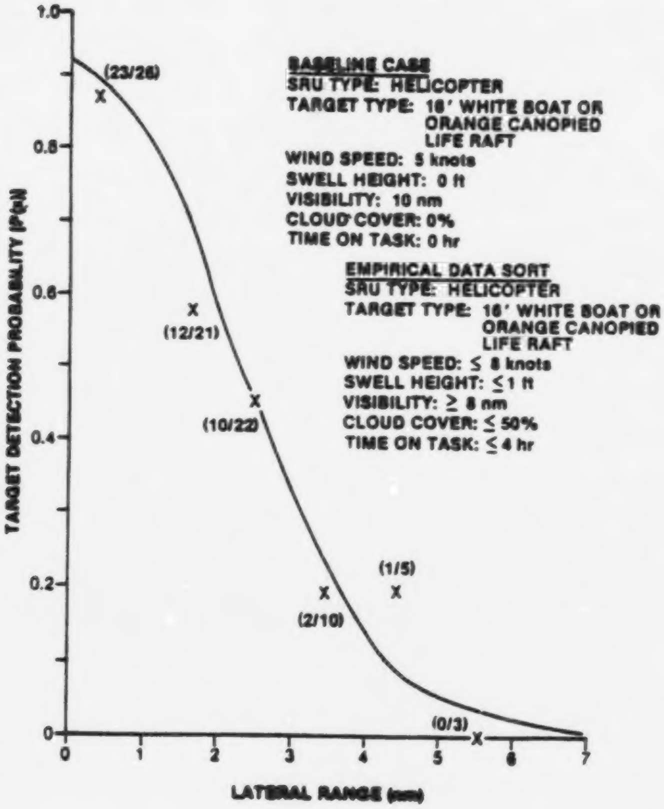


FIGURE 3.8 COMPUTED AND ACTUAL P(x) VERSUS LATERAL RANGE FOR BASELINE CASE
(helicopters searching for white 16-foot boats or orange canopied life rafts)
(Edwards et al, 1981)

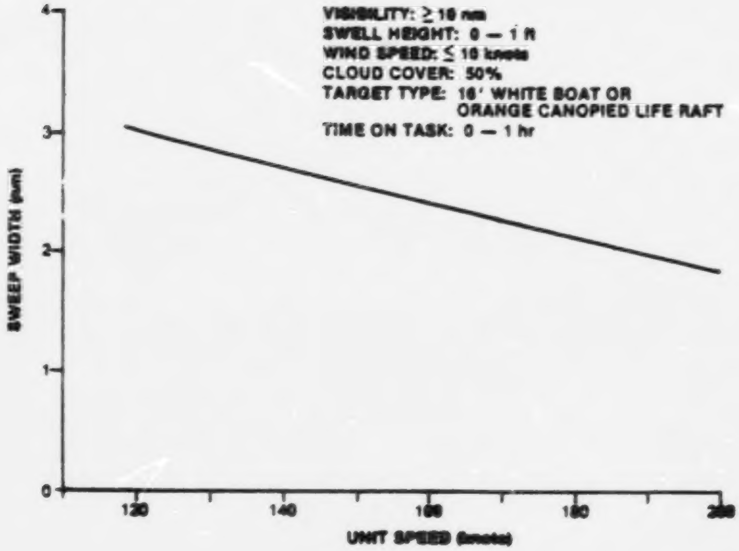


FIGURE 3.9 INFLUENCE OF SEARCH SPEED ON FIXED-WING AIRCRAFT SWEEP WIDTH (16-foot boat target)

(Edwards et al, 1981)

TABLE 3.7

EMPIRICAL RESULTS SORTED ON SEARCH SPEED FOR FIXED-WING AIRCRAFT
(16-foot boat targets)
(Edwards et al, 1981)

SEARCH SPEED (knots)	LATERAL RANGE (nm)				
	0-1	1-2	2-3	3-4	>4
<130	(12/18) 0.67	(11/19) 0.58	(3/12) 0.25	(2/13) 0.15	(0/4) 0.0
130-160	(43/66) 0.65	(21/53) 0.40	(10/49) 0.20	(4/28) 0.14	(1/12) 0.08
>160	(33/50) 0.66	(14/35) 0.40	(3/35) 0.09	(0/9) 0.0	(0/2) 0.0

NOTE: The number in parentheses is the ratio of detections/opportunities; the number below is the ratio as a decimal.

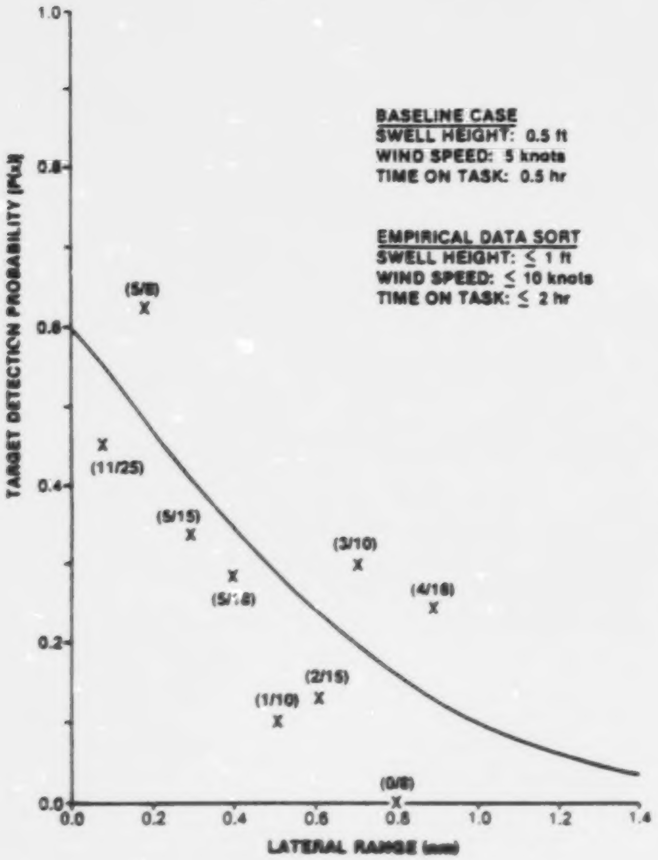


FIGURE 3.10 PREDICTED AND ACTUAL P(x) VERSUS
LATERAL RANGE FOR BASELINE CASE
(aircraft searching for PIWs)

(Edwards et al, 1981)

TABLE 3.8

INFLUENCE ON P(x) OF CHANGES IN SIGNIFICANT PARAMETERS — AIRCRAFT SEARCHING FOR PIWs

(Edwards et al, 1981)

SIGNIFICANT PARAMETERS			PROBABILITY OF DETECTION*	
PARAMETER(S)	BASELINE VALUES	MODIFIED VALUES	BASELINE CASE	MODIFIED CASE
Wind speed and swell height	5 knots and 0.5 ft	15 knots and 3 ft	0.47	0.19
Time on task	0.5 hr	2 hr	0.47	0.26

*Predicted P(x) at a lateral range of 0.2 nm.

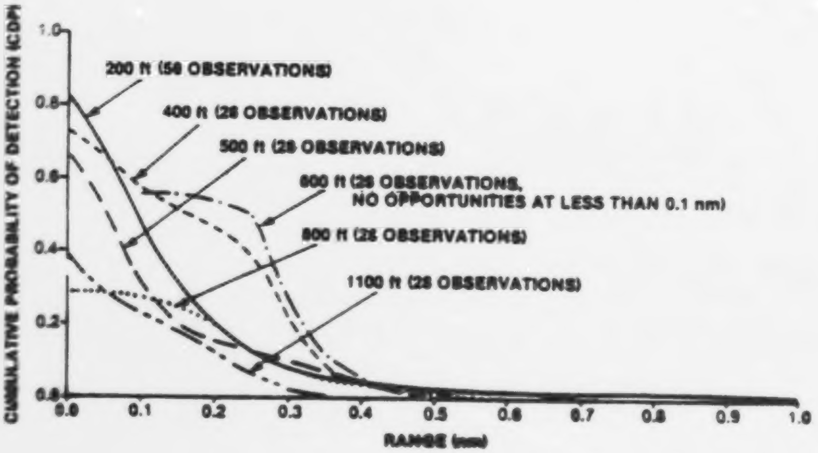


FIGURE 3.11 CDP VERSUS RANGE CURVES FOR PIWs
(Edwards et al, 1981)

TABLE 3.9

SWEEP WIDTHS FOR AIRCRAFT SEARCHING FOR PIWs
(Edwards et al, 1981)

SWEEP WIDTH (nm)	WIND SPEED (knots)	SWELL HEIGHT (ft)	TIME ON TASK (hr)
0.7	≤10	0-1	0-1
0.5	≤10	0-1	1-2
0.3	≤10	0-1	>2
0.3	15	2-3	0-1
0.2	15	2-3	1-2
0.1	15	2-3	>2
0.1	20	4-5	0-1
0.1	20	4-5	1-2
0.1	20	4-5	>2

width, must be known. Secondly, the effect of navigational inaccuracies convoluted with the lateral range curve results in a flatter curve, which pushes the POD toward the random search assumption. Third, the less uniform the target density, the higher the POD in the central parts of the search area and the lower the POD in the search border areas.

3.1.2 Electro-Optical Sensors

3.1.2.1 Television

3.1.2.1.1 Literature Review

The review of literature did not identify any papers or reports where television systems, as a major sensor, were tested for small object detection. This appears to be partly because none of the search and rescue agencies utilize television systems in their operations and partly because television is an extension of the human eye and often overlooked. Yet, television systems are used for surveillance by military and police forces, and have been used and are recommended as part of most airborne pollution monitoring systems (O'Neil et al, 1981). Television as an airborne sensing system has been reported by Worsfold et al, (1972), de Villiers (1973), Edgerton et al (1975), Lapp (1975), Grover and King (1977), O'Neil et al (1980) and FGBAL (1984). None of these studies was concerned with small objects or targets except the FGBAL (1984) report which investigated small quantities of pollutants (typically one barrel of oil). A report by Remotec (1980) recommended the testing of a low light level television (LLLTV) as part of a survey suite for sea ice and iceberg detection but television was the one sensor left out of the field test.

3.1.2.1.2 Sensor Description

The visible portion of the electromagnetic spectrum as seen by the human observer can be recorded by television systems. The sensitivity of the television tube is similar to that of the human eye and can be extended to the ultraviolet and near-infrared. Television sensitivity can also be extended to low light levels where the human observer cannot see. LLLTV cameras represent the greatest sensitivity range for television/electro-optical systems, and the following discussion is mainly concerned with this type of system. LLLTVs can produce a scene at night representative of what the human eye can see during the day. Therefore, they extend the observation period and specialized camera tubes can improve and/or enhance any portion of the total operating range sensed, hence performance figures for LLLTVs represent the maximum that can be expected from television systems.

LLLTVs are mainly used as night-seeing devices for the military and for security services. The baseline study for LLLTV was carried out by Theudorou and Pickels (1971). This information defined all parameters and characteristics of LLLTV and assisted in establishing the silicon tube as the current industry standard.

An ordinary, standard television camera cannot operate in total darkness or low light conditions because of the absence of illumination. Vision in the human eye occurs when rods and cones transform the radiant power of light into impulses registered in the brain. The rods account for scotopic vision and the cones for photopic vision. The two types of vision are sensitive to different wavelengths of radiation (Figure 3.12). LLLTV can register and record illumination in the scotopic region, a region of low natural illuminance (Figure 3.13). The intensity or brightness of light and the spectral distribution of colour range are two important characteristics of illumination, whether natural or manmade. Natural illumination has a broad spectrum from the ultraviolet through to the near infrared. Sunlight peaks in the blue-green region and natural light in the near infrared. Table 3.10 shows the scene illumination resulting from typical natural illumination sources. The intensities and spectral

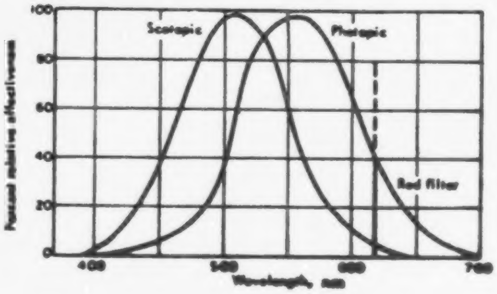


FIGURE 3.12 LUMINOSITY CURVES FOR SCOTOPIC (rod) and PHOTOPIC (cone) VISION
(REMOTEC, 1980)

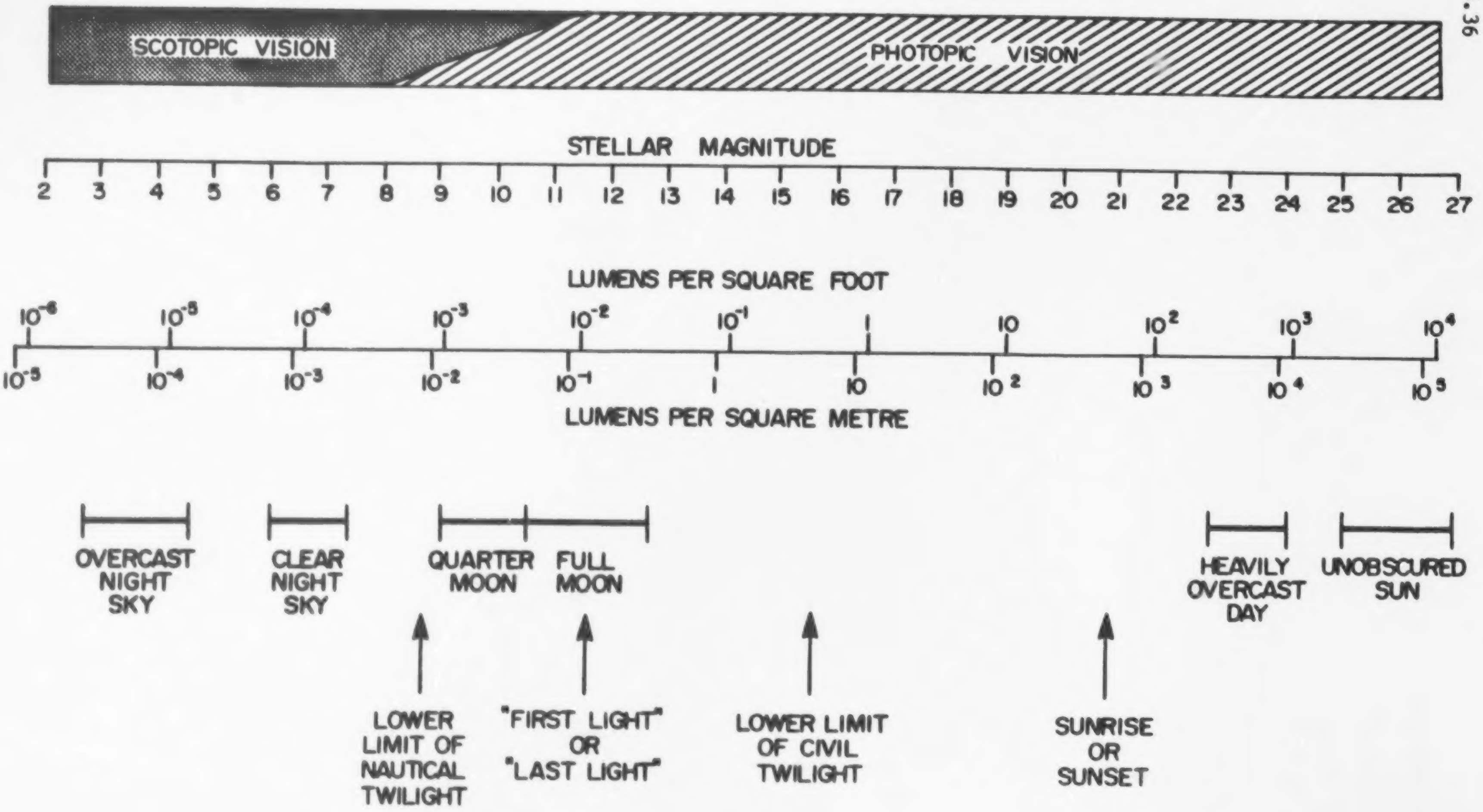


FIGURE 3.13 RANGE OF NATURAL ILLUMINANCE LEVELS

TABLE 3.10

SCENE ILLUMINATION RESULTING FROM TYPICAL NATURAL ILLUMINATION SOURCES

(REMOTEC, 1980)

NATURAL ILLUMINATION SOURCE	SCENE ILLUMINATION Lumens/square foot (foot-candles)
Full Sunlight	1,000 to 10,000
Overcast Day	10 to 1,000
Twilight	1
Deep Twilight	0.1
Full Moon, Clear	0.01 to 0.1
*Full Moon, Overcast	0.001 to 0.01
Quarter Moon, Clear	0.001
Starlight, Clear	0.0001
*Starlight, Overcast	0.00001

*In inhabited or industrial areas, the ambient illumination will be greater because of reflection of man-made illumination.

distribution of manmade illumination covers a broad and varied range. However, television cameras are referenced to a standard, allowing consistency of specifications and a reasonable basis for comparisons.

The scene that is being observed or sensed has an influence on any measurement program. For example, if the scene illumination is flat (not from a point source), the amount of light that reaches a sensor will be primarily determined by the scene reflection characteristics, while for illumination from a point source such as a spotlight, the amount of light that reaches the sensor will be determined by the angle of incidence of the light and the reflection characteristics of the scene. Reflection characteristics depend on such things as surface texture and reflectance properties. Reflectance, like illumination, varies with time.

The physical size of the viewing area is important in determining the physical attributes of the sensor, such as the choice of viewing lens. The lens controls the size of the area to be viewed. Scene reflectance changes from wide-angle viewing to narrow-angle viewing. Focal length and depth of field also influence image quality.

Secondary electron conduction (SEC) and silicon intensifier target (SIT) tubes are the generic tube types normally used in LLLTV viewing, the SIT being favoured. Additional intensifiers can be mounted in front of the tubes. The SIT is also known as an EBIR or SEBIR. The intensifiers are coupled to the faceplate of the tube using fibre optics. Intensifiers help to overcome problems of sensitivity, blooming and image lag, although at the lowest light levels these same intensifiers can contribute to the same problems.

As previously stated, LLLTV is comparable to any ordinary television system. A camera views a scene, displays it on a monitor, and records it on a video tape or makes a hard copy of the image scene. LLLTVs are normally used to image where scene illumination is below the threshold limit of the human eye, while more ordinary television systems can be used to replace the human eye and record the permanent record of the viewed scene.

The major parameters that must be considered in LLLTV and other television systems are as follows:

(i) Resolution,
(ii) Lag,
(iii) Blooming,
(iv) Responsivity,
(v) Signal-to-noise ratio, and
(vi) Dynamic range.

SIT tubes provide the best resolution at lower light levels while standard television vidicons have no low light level capability. Lag is a function of target area. The smaller the area, the less the lag. SIT tubes have the lowest lag because of inherent higher gain and reduced target size caused by system optics. If lag exceeds 20% the target will smear due to sensor motion. Blooming is a phenomenon associated with spreading of a high light image. It occurs with sudden increases in illumination. SIT tubes have the best bloom control of all television tubes. Responsivity varies for different types of camera tubes. It is the ratio of output current to individual flux. If plotted, the slope of the curve is called the gamma of the tube type. A low gamma can handle a higher range of input light levels. The dynamic range is defined as the range of light conditions in which a camera will operate without damage to the tube or loss of information. The higher the dynamic range, the broader the range of light conditions within which the camera can operate. Starlight to full sunlight represents a dynamic range of 4 billion:1. Intensifiers can be used to accomplish full range, but under high light conditions there can be a loss of resolution, sensitivity and blooming.

A basic television camera system consists of the following:

(i) Camera (LLLTV or vidicon),
(ii) Zoom lens,
(iii) Housing,
(iv) Mount,
(v) Time/Date generator,
(vi) Monitor,
(vii) Video recorder, and
(viii) Greytone recorder.

This configuration would meet all requirements of observation.

It should also be noted that a system called a "laser gated television system" is available. This is in some respects an active/passive system. The passive television detects a target, a laser portion defines a range to the target, an automatic field of view occurs with an automatic zoom lens, and the scene zooms in on the target for identification. This system is used with televisions with some low light sensitivity, but is restricted, as the active laser light source would cause blooming problems with the more sensitive LLLTV tubes.

The types of cameras and camera tubes available are extensive. Table 3.11 presents a partial list of the available specifications of some television camera types.

3.1.2.1.3 Probability of Detection

No information on POD was obtained from the literature. Until testing is carried out it must be assumed that POD results are similar to the human observer results for lateral range curves, but sweep widths might improve because many human imperfections are removed. The prime factor in television observation is sensitivity.

TABLE 3.11

TYPES OF TELEVISION CAMERAS

(Bercha, 1984)

	SIZE	FORMAT SIZE	RESOLUTION	LENS	LIGHT SENSITIVITY (FC)	SPECTRAL RESPONSE	RECORDING MEDIUM	WEIGHT	POWER	POLARIZATION
Vidicon Camera	80x60x154 (mm)	9.5x12.8 (mm)	500 lens at center (horizontal)	8 to 50 (mm)	1 (minimum)	350-850 (nm)	Magnetic tape	.58 to 1.5 kg	3.6 Watts	
LLLTV (typical)		9.5x12.8 (mm)	13 to 30 (L/mm)	12.5 mm (auto iris)	Starlight to full sun	350-850 (nm)	Magnetic tape	69 kg	26 Watts	
TeleVision R181-TN CCTV Camera System	380x100 (mm)		Horizontal center: 450 lines min.	9 mm f/1.4	9 foot candles		Black & White Monitor	(total) 28.5 lbs	12.5 VDC	
RCA TC 103 H LLLTV				Fujinon TV LH 15A2 f/1.4, 12.5 (mm)		350-850 (nm) full width	IVC Model 815AA Video tape recorder (1" tape)	69 kg	110V 60 Hz 4.2A	Polaroid HNP's Horizontal (240-740)
EBV Camera (typical)	80x60x154 (mm)	22.8x22.8 (mm)	70 L/mm	8 to 50 mm (or fixed auto iris)	0.05 (minimum)	350-850 (nm)	Magnetic tape	225 kg	60 Watts	
AOSS LLLTV (UV)				f/1.4	S/N=7 for Visual (quarter moon)	0.32-0.40 (um)	B&W TV Monitor			FOV=15° Horizontal & Vertical (across spectrum)
AOSS LLLTV (visible)				f/5.6, f/4.5	S/N=7 for UV quarter moon	0.40-0.80 (um)	B&W TV Monitor			FOV=8° & 26° Horizontal & Vertical (across spectrum)
IDT Inc. Model SL-1983 SIT-LLLTV	15x11x32 (cm)		H=700 L/center 600 L/corners V=350 L/min		1×10^{-4} foot-candles	3,500-8,300 Å	Television Display	10 lbs 4.5 kg	100-135/200-270 VAC 50/60 Hz, 21 Watts 25 VA	Horizontal and Vertical
Marconi Avionics LLLTV V0084		FOV 2.66°x2.00° (46.5 mrad x 35 mrad)	440-490 lines in center	16mm Intensifier Ebsicon	Bright sun-light to star-light		Television Display	42.5 kg (total)	100-125/200-250V, 40-400 Hz, 70 VA	Horizontal and Vertical
Marconi Avionics Lowlight Day Modular TV V3341-V3344			Typical 500 lines/picture height	276 mm or 25-500 mm	Daylight or lowlight		Video Recording		100-125V 200-250V 50/60 Hz	

Sensitivity is a measure of the ability of a camera to image a scene. In the visible spectrum the coverage or range observation is governed by the optical horizon (Figure 3.14) and can be expressed as 2.07 x the square root of the sensor height above sea level. The resulting curve is parabolic at low altitudes above sea level and tends toward a linear relationship between 2500' and 3000' above sea level with an optical horizon greater than 100 nm. The ability to detect small objects will depend on the resolution of both the camera and the recording devices, especially the video monitor. The least resolution of any component in the system will be the governing factor. The result is that the maximum detection range for a particular target may be less than the maximum range of observation. Attenuation by the atmosphere will decrease the target-to-background contrast resulting in insufficient contrast for operator recognition. To fully define the maximum recognition range, a number of parameters must be considered, including contrast, magnification, photographic power of the camera lens, atmospheric attenuation, type of illumination and sensor height.

The amount of reflected light from any object is the luminance, which is dependent on the reflective coefficient of the object. Different materials have different reflective coefficients resulting in variations in scene brightness. The variations are called 'image contrast', and if the contrast is detectable, a target will be seen on a background. Two types of illumination, diffuse and direct, occur. Diffuse illumination results when radiation occurs equally from all parts of the sky, such as in the case of an overcast condition. Direction illumination results from point sources of light such as the full moon or a clear sky. Shadows occur in the case of direct illumination and can be used to enhance target detection.

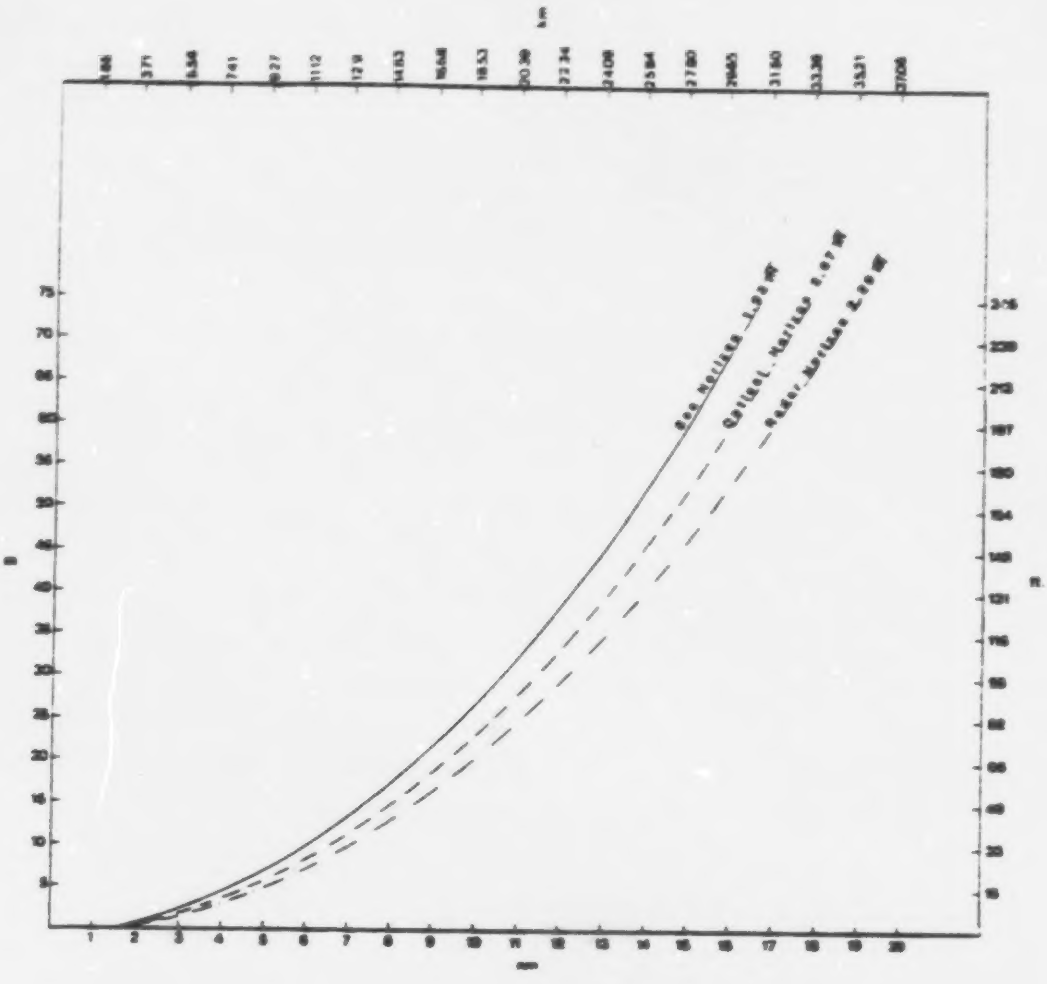


FIGURE 3.14 SENSOR RANGE AS A FUNCTION OF SYSTEM MOUNTING HEIGHT (REMOTEC, 1980)

A mathematical expression is used to determine target contrast under diffuse scene illumination conditions:

$$C_0 = \frac{(R_T - R_B)}{RB}$$

where C_0 = contrast at the target.
R_T = target reflectivity coefficient.
R_B = background reflectivity coefficient for diffuse scene illumination.

This formula shows that luminance range is dependent upon the range of the reflection coefficient of targets and backgrounds within the scene. Sky background is a special case where R_B is unity and contrast reduces to R_T^{-1} giving a negative contrast, which can be interpreted as a dark shape on the horizon. If a small target was an iceberg which has a reflectivity of 0.7, the target-to-sky background is -0.3. If the reflection coefficient for water is 0.28, the target-to-water contrast is 1.5. This shows that a target may be detected due to either light or dark contrast.

In the case of direct illumination, shadows will occur in the scene due to surface relief. The shadow area can be part of the target or background. Vertical heights of targets would produce the most notable shadows. Shadows will not appear completely black because diffuse light from the sky due to other sources such as starlight will govern the magnitude of the shadow luminance. Contrast between shadow areas and points of the target illuminated by direct light will depend on the intensity of the direct light and will be greater than the diffuse lighting contrast. Detection will be easier as it is proportional to the amount of direct lighting.

Sea and sky background reflection coefficients change constantly because of changes in oceanographic and atmospheric conditions. For example, sea state will make the ocean surface increasingly rough, or a partial changing cloud cover will have changing shadow patterns. The result would be that a target with constant luminance would have varying contrast.

As the range between the detector and target increases, the luminance from the target decreases. The decrease follows an inverse square law in free space. In the real world, where the atmosphere is present between the sensor and the target, a further decrease due to atmspheric conditions will occur. Conditions such as rain or fog will greatly reduce the observation range. The observation range can be defined as the range at which the target/background contrast produces a threshold level at the sensor lens. In meteorological terms, the range is called the "visibility range" and is defined as the range at which the contrast of an object against the horizon sky reduces to 0.02 (Figure 3.15). Camera sensitivity is non-linear at extremely low light scene illuminations; thus, higher than normal contrasts are necessary.

Because the atmosphere affects the luminance, the contrast ratio (C_0) is also affected. C_0 at the camera is the apparent contrast ratio (C_R) calculated as:

$$C_R = C_0 e^{-\delta R} .$$

where R = range from sensor to target,

δ = atmospheric attenuation coefficient.

The attenuation coefficient varies with atmospheric clarity (Table 3.12). The equation shows that as the range increases the apparent contrast available decreases and that below a threshold level C_R will be undetectible.

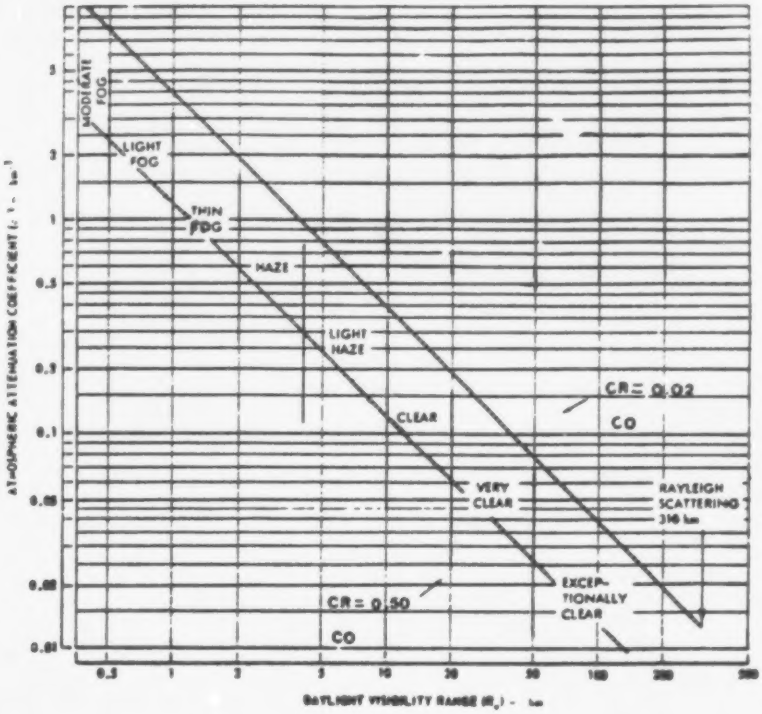


FIGURE 3.15a ATMOSPHERIC ATTENUATION COEFFICENT FOR VISIBLE LIGHT AS A FUNCTION OF DAYLIGHT VISIBILITY RANGE
(Electro Optic Handbook, 1974)

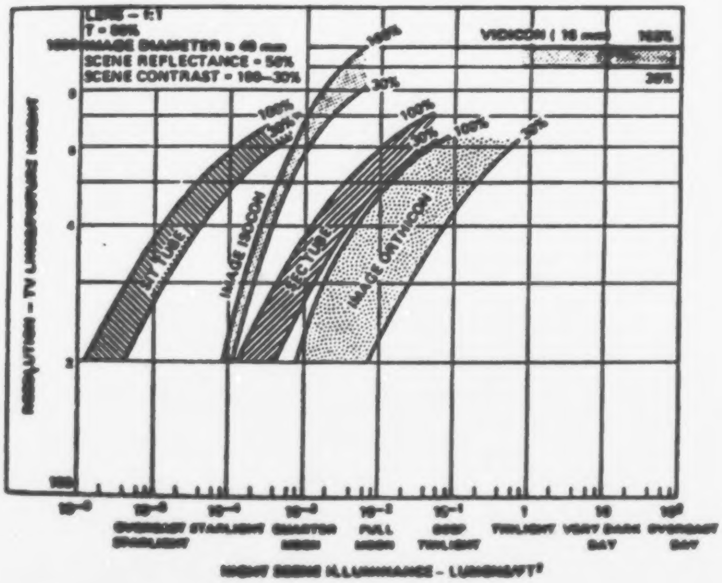


FIGURE 3.15b COMPARISON OF FIVE BASIC CAMERA TYPES SHOWING THE STATIC RESOLUTION CAPACITY AS A FUNCTION OF SCENE ILLUMINATION

(Electro Optic Handbook, 1974)

TABLE 3.12

MAXIMUM RANGE OF DETECTION VS ATMOSPHERIC "CLARITY"

ATMOSPHERIC CONDITIONS	δ	MAX. RANGE km.
VERY CLEAR	.10	11.31
STANDARD CLEAR	.17	6.68
CLEAR	.26	4.25
LIGHT HAZE	.49	2.27
MEDIUM HAZE	.78	1.42
HAZE	1.30	0.85
LIGHT FOG	4.89	0.23

TABLE 3.13

MAXIMUM RANGE OF DETECTION VS RAINFALL RATE

RAINFALL DESCRIPTION	RATE mm/hr	MAX. RANGE km.
DRIZZLE	0.5	7.11
LIGHT RAIN	1.0	4.47
MODERATE RAIN	4	1.77
HEAVY RAIN	16	0.70
EXCESSIVE RAIN	40	0.38

Note: MAXIMUM RANGE WILL INCREASE WITH INCREASES IN TARGET TO BACKGROUND CONTRAST WHICH CAN OCCUR UNDER DIRECT LIGHT CONDITIONS (I.E. HALF-MOON, CLEAR SKY).

TABLES 3 AND 4 WERE GENERATED WITH A THRESHOLD LEVEL APPARENT CONTRAST OF 0.5 AND AN INHERENT CONTRAST OF 1.52.

Modifying the equation for C_R gives:

$$R_M = \frac{-\ln (C_M/C_O)}{\delta}$$

where C_M = threshold contrast,

R_M = maximuim range of target detection for a specific target-to-background contrast.

With an inherent contrast of 1.52 and a threshold level of apparent contrast of 0.5, maximum detection ranges can be calculated for this set of conditions (Table 3.12). These results show that atmospheric clarity is very important and that humidity affects the clarity because as the humidity builds up, so do the aerosol particles that constitute the haze. When seas become rough, ocean spray will further reduce the clarity.

The effects of precipitation can be seen by using the following formula to calculate the attenuation coefficient for rainfall:

$$\delta_r = 0.248\ r^{0.67}$$

where r = rainfall rate in mm/hr.

δ_r = rainfall attenuation coefficient in km.

Substituting this equation in the R_M equation, the maximum range of detection can be stated as:

$$R_M = \frac{-\ln (C_M/C_O)}{0.248r^{0.67}}$$

Using the previously used values of C_M and C_O, Table 3.13 can be produced. Snowfall will have comparable effects.

The maximum observation range was previously expressed by the optical horizon expression. The higher the camera, the greater the range. Provided the platform is relatively stable, electronic distortions such as image lag should not be a problem. It appears that with airborne sensor platforms the limiting conditions will be atmospheric conditions, illumination, and resolution range. Resolution range can be increased by using telephoto lenses, but trade-offs will occur because telephoto lenses reduce the field of view, thereby decreasing the number of targets that can be observed in a single frame. Values of maximum resolvable range versus target height for 2- and 4-line pairs resolved on a video monitor are given in Table 3.14. The values show that the requirement for greater spatial resolution affects the maximum range resolution. The table also shows the effect due to field of view changes. The resolvable range increases as the field of view decreases. This shows that consideration must be given to the search scene, as a target may be resolvable under one field of view and not the other.

The performance of an imaging sensor can be evaluated using a model. One model (Bailey, 1970) defines the probability that a target will be recognized on a display as:

$$P_r = P_1 P_2 P_3 \eta \ .$$

where: P_r = probability target well be recognized on the display.

P_1 = probability that observer looks for a specific glimpse time (1/3 S) in the direction of the target.

P_2 = probability that if the displayed target image is viewed for one glimpse period, it will have sufficient contrast and size to be detected.

P_3 = probability that if a target is detected, there will be enough detail for it to be recognized in a single glimpse.

η = degradation factor arising from noise.

s = visual search time.

TABLE 3.14

MAXIMUM RANGE OF RESOLUTION VS VERTICAL DIMENSION OF TARGET

VERTICAL TARGET HT. (m)	MAXIMUM RANGE IN KILOMETERS with 2 line pairs resolved 46 F.O.V.	5 F.O.V.	with 4 line pairs resolved 46 F.O.V.	5 F.O.V.
1	0.11	1.0	0.05	0.50
15	1.63	15.0	0.82	7.52
45	4.90	>15	2.45	>15
75	8.17	>15	4.09	>15

The visual search time is the time required to search a visual frame and is computed analytically from knowledge of the eye's fixation time and the angular size of the display (Sinion, 1965). Two assumptions are made:

(i) A single fixation requires approximately 0.3 seconds, (s).
(ii) Circular field of clear vision subtends 5°.

Therefore, the length of time required to search an entire display once is computed by determining the number of nonoverlapping 5° fixations. For example, a display subtending 16° x 16° at the eye would give:

$$16^\circ/5^\circ \times 16^\circ/5^\circ \times 0.3\text{s} = 3.1 \text{ s.}$$

In the model, P_1 is determined by:

$$P_1 = 1 - \exp\left[-\left(\frac{700}{G}\right)\left(\frac{a_t}{A_s}\right)t\right]$$

where a_t = area of target.
A_s = area to be searched.
t = time.

G = congestion factor, usually between 1 and 10, for most real imagery of interest.

The probability of detection (P_2) at the threshold constant (C_m) is by definition 50%. For other contrasts (C) the following approximation is used:

$$P_2 \cong 1/2 \pm 1/2 \sqrt{1-\exp\left[-4.2\,(C/C_M - 1)^2\right]}$$

where the minus sign is used when $C < C_M$. P_3 and η are calculated respectively from:

$$P_3 = \begin{bmatrix} 1 - \exp[-(N_r/2-1)^2] & N_r > 2 \\ 0 & N_r \leq 2 \end{bmatrix}$$

and

$$\eta = \begin{bmatrix} 1 - \exp[-(SNR-1)] & SN_r > 2 \\ 0 & SN_r \leq 2 \end{bmatrix}$$

where

$$N_r = \frac{L_{min}}{\alpha R}$$

where N_r is the number of resolution cells contained in the minimum projected target dimension L_{min}, α is the angular resolution of the sensor, R is the target range and SNR is the signal-to-noise ratio.

If only detection without recognition is required, the probability of detection (P_d) is given as:

$$P_d = P_1 P_2 \eta \, .$$

For practical detection and recognition probability, P_d and P_r can be expressed as a function of the number of cycles of limiting resolution equivalent to the critical target dimension (minimum height or width). Figure 3.16 shows a quick method of determining probability. This figure has been used to make the nomograph given in Figure 3.17.

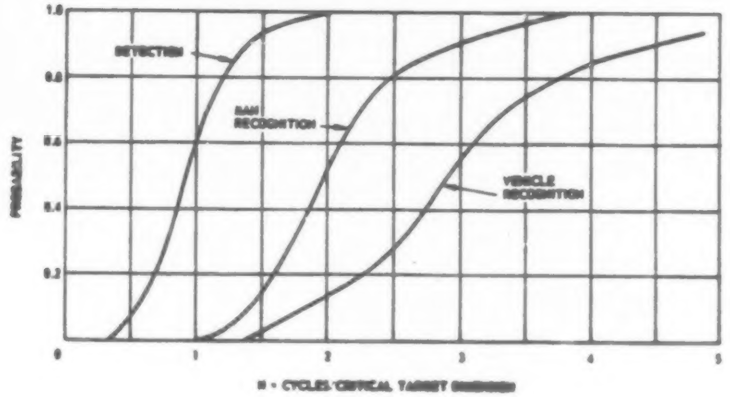


FIGURE 3.16 PROBABILITY OF DETECTION AND RECOGNITION AS A FUNCTION OF SYSTEM RESOLUTION ACROSS CRITICAL TARGET DIMENSIONS (U.S. Night Vision Laboratory, Fort Belvoir, VA)

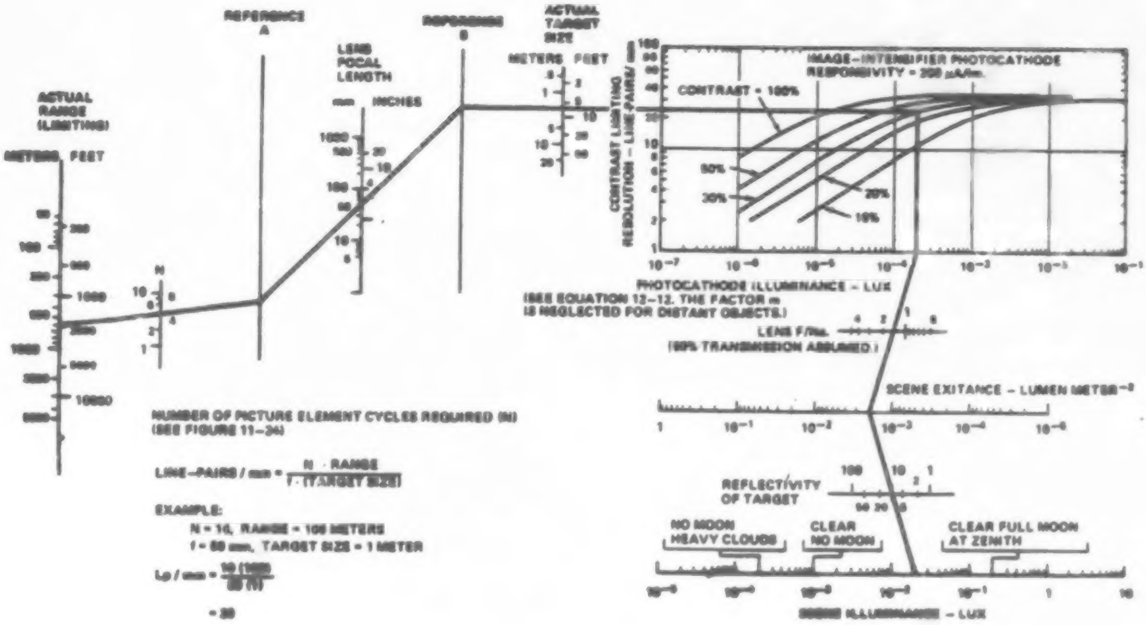


FIGURE 3.17 NOMOGRAPH FOR DETERMINING PERFORMANCE PARAMETERS OF A LOW-LIGHT-LEVEL IMAGE INTENSIFIER TARGET DETECTION OR RECOGNITION SYSTEM
(Electro Optics Handbook, 1974)

The shapes of limiting resolution curves come from:

$$\frac{1}{R^2} = \frac{1}{R_s^{\ 2}} + \frac{1}{R_t^{\ 2}} .$$

where R = combined resolution limit.
R_s = statistical resolution.
R_t = inherent tube resolution.

3.1.2.2 Forward-Looking Infrared (FLIR)

3.1.2.2.1 Literature Review

The U.S.C.G. has carried out search and rescue trials with FLIR systems as part of their recent program to update and upgrade the search and rescue manual. The results of the investigation are presented in Hover et al (1982). The study was concerned with three classes of targets: 5 - 6 m boats, 4- and 7-man life rafts, and simulated PIWs. The FLIR used has two fields of view (10°x13.3° and 30°x40°), two video polarities, automatic target tracking and two automatic search modes (step or scan). The narrow field of view mode provided 1X magnification, while the wide field of view mode provided 3x magnification. The FLIR was mounted in a turret that provided azimuthal coverage of ±90° and depression/elevation coverage from -80° to 30°. The FLIR had a minimum resolvable temperature that was better than 1°C. Flight altitudes varied from 61 to 457 m, and early in the experiment it was demonstrated that the narrow field of view mode could not provide sufficient area coverage for searching but was useful for target classification.

The study (Hover et al, 1982) found that the following parameters had significant influence on FLIR detection performances:

(i) Small boat and life raft targets:
- sea condition.
- range to target.
- field of view.
- target type.

(ii) PIW targets:
- sea condition.
- altitude.
- video polarity.
- range to target.
- field of view.

These parameters were noted in cumulative probability-of-detection curves obtained from the experimental data. The study was concerned only with testing the capability of an off-the-shelf system. Other potential developments such as digital image enhancement were not assessed.

Further testing was carried out in 1983 using a different model of FLIR (Author Unknown, 1983). The test was carried out using randomly placed small boats, life rafts and simulated PIWs. Search altitudes were 1000' for small boats/-life rafts and 500' for PIWs. It was concluded that this FLIR system could detect small boats and life rafts at ranges out to 1.5 nm; that PIWs were difficult to detect under the range of environmental conditions encountered (wind speed 6-18 kts and significant wave heights of 1.5' - 4.0'); that the simulated PIWs may not be giving off a strong enough thermal signal, hence PIW results were inconclusive; that a wide search field of view and a narrow search field of view for identification are probably needed; that quantitative controls for azimuth/range calibration and focus/level adjustments are needed; that FLIR should look directly ahead from a nose mount and not a side mount and that the model FLIR tested was an effective search and rescue sensor. The report recommended that range-finding capability is necessary, that precise azimuth and depression angle measurement is required, that two fields of view are necessary, and that a number of system control/function improvements are necessary.

In a report by Nash et al. (1982), FLIR systems are discussed as an adjunct to a radar program. This study analyzed video tapes of FLIR search data to estimate the amount of detection performance degradation occurring due to the human operator. The report made tentative conclusions on degradation due to operator limitations and recommended further testing because only a limited data base existed. The study was concerned with small boats, life rafts, and simulated PIWs, and data were collected both day and night. The limited data set showed that probability of detection decreased significantly for all targets when the significant wave height exceeded 2', and that the mean detection range decreased significantly under the same wave motions.

3.1.2.2.2 Sensor Description

There are two types of infrared viewing systems: those that look directly down and those that look forward or out at an angle. Forward-Looking Infrared (FLIR) are of the second type. The first type will be discussed under vertical scanners. FLIRs operate only in the infrared portion of the electromagnetic spectrum, either in the 3 - 5 micron or 8 - 14 micron range. Included in the FLIR categories are scanning systems, thermovisions, and pyroelectric vidicons. The pyroelectric vidicon does not have the sensitivity that is normally required for search and rescue applications as it is basically a staring sensor that builds up a signal like a storage device and needs to refresh the faceplate. A moving aircraft would cause mechanical problems with pyroelectric vidicons as the platform, target, and target background move. The thermovisions are similar to the FLIR type systems in that the scene is scanned in some format; they are really a subclass of FLIR. They are mentioned because the AGA, and Barr and Stroud type systems can be used for quantitative data gathering and are excellent for studies where quantitatitve thermal data on targets and backgrounds are required. The FLIR in operational use is a scanning infrared system; normally vertical scanning is preferred because the horizon does not become muddled, as it would in horizontal scanning. The FLIR can be considered the counterpart of a television system operating in the infrared portion of the electromagnetic spectrum. Controls are similar, lenses are used to collect scene data, and scene and recording devices are somewhat generic. Table 3.15 gives some examples of commercially available FLIR systems with available specifications.

3.1.2.2.3 Probability of Detection

Nash et al (1982) reported on FLIR analysis by the U.S.C.G. This study consisted of 167 detection opportunities with 115 real-time detections and 120 post- analysis detections. This indicates operator performance degradation in real time. It was also found that in postflight analysis of the FLIR video tapes detection was effected quicker than in the field, which translated into an increase in detection range of almost 0.1 nm at a ground speed of 60 kts. Table 3.16 compares the real-time and post-flight analysis for the FLIR data under specific significant wave height conditions. The FLIR was not tested under a wide enough range to make conclusive comments concerning P(x) vs. later range and sweep widths.

The results of Hover et al (1982) and Osmer et al. (1982) presented preliminary cumulative detection probability data for FLIR systems for small boats, life rafts and PIWs (Figure 3.18). These are data for two classes of sea state and two classes of targets.

TABLE 3.15

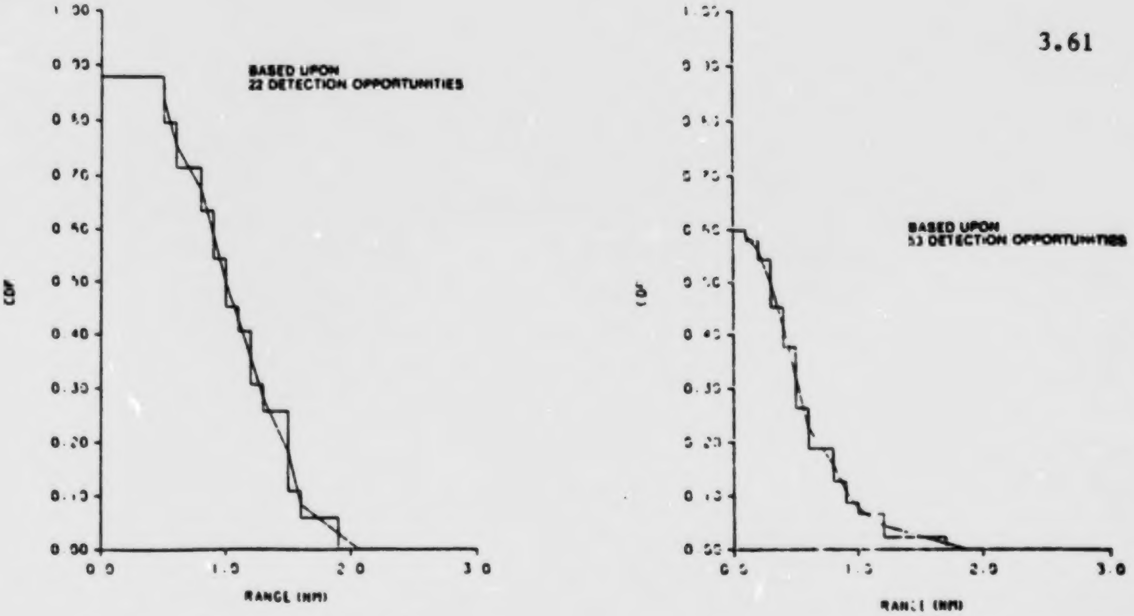
EXAMPLES OF SOME COMMERCIALLY AVAILABLE FORWARD LOOKING INFRARED DEVICES (FLIR)
(Bercha, 1984)

MANUFACTURER	MODEL [illegible]	HORIZONTAL FOV DEGREES	VERTICAL FOV DEGREES	IFOV (SQUARE) (mrad)	TYPICAL NETD (C° @ CLEAR)	MRTD (C°)	EQUIVALENT FOCAL LENGTH (CM)	EQUIVALENT F/NO.	MAGNIFICATION	TRANSMITTANCE (PERCENT)	RANGE OF FOCUS (ft)	FOV CHANGE TIME (sec)	WEIGHT (IN SENSOR) (lbs/kg)	DETECTOR TYPE	NO. OF ELEMENTS	TYPICAL D* (λP)	P (PEAK WAVE-LENGTH)	COOLANT	COOLDOWN TIME	COOLANT RUN TIME
FLIR Systems Inc.	1000 B	28	17	1.9	.2 @ .27	.1	2.71	.85	1x	70	5 to infinity	N/A	18.5/8.4	HgCdTe	2 (row of 1)	$4x10^{10}$ cm $Hz^{1/2}$ W^{-1}	10.6µ	Compressed argon	10 seconds (initial) stable in 3 minutes	6 to 8 hours (continuous) before refill
FLIR Systems Inc.	1500 A	40	26	2.7	.2 @ .19	.1	1.9	.85	1x	70	5 to infinity	N/A	18.5/8.4	HgCdTe	2 (row of 1)	$4x10^{10}$ cm $Hz^{1/2}$ W^{-1}	10.6µ	Compressed argon	10 seconds (initial) stable in 3 minutes	6 to 8 hours (continuous) before refill
FLIR Systems Inc.	2000 A (Wide) (Narrow)	28 7	17 4	1.9 .47	.2 @ .27 .3 @ 1.08	.1 .15	2.71 10.8	.85 .85	1x 4x	70 65	5 to infinity 25 to infinity	.06 .06	26/11.8 26/11.8	HgCdTe	2 (row of 1)	$4x10^{10}$ cm $Hz^{1/2}$ W^{-1}	10.6µ	Compressed argon	10 seconds (initial) stable in 3 minutes	6 to 8 hours (continuous) before refill
FLIR Systems Inc.	2500 A (Wide) (Narrow)	40 7	26 4	2.7 .47	.2 @ .19 .3 @ 1.08	.1 .15	1.9 10.8	.85 .85	1x 4x	70 60	5 to infinity 25 to infinity	.06 .05	26/11.8 26/11.8	HgCdTe	2 (row of 1)	$4x10^{10}$ cm $Hz^{1/2}$ W^{-1}	10.6µ	Compressed argon	10 seconds (initial) stable in 3 minutes	6 to 8 hours (continuous) before refill
Honeywell	[illegible] (Wide) (Narrow)	11.5° 3°	7.5° 2°				3.66 12.09	1.22 1.22	3.18x 12.16x				6.8kg	(Hg,Cd)Te			7.5–11.5 µ	Compressed N_2	30 seconds (maximum)	3 hours (minimum)
Lockheed California Company	CO-60/AA (Wide) (Narrow)	FOV 15°x20° 5°x6.67°											130	HgCdTe			10µ			
Aeronutronic	Miniflir	FOV 30°x40°											77.3	HgCdTe	2		8–12µm	Compressed argon	10 seconds (initial) stable in 3 minutes	6 to 8 hours (continuous) before refill

TABLE 3.16

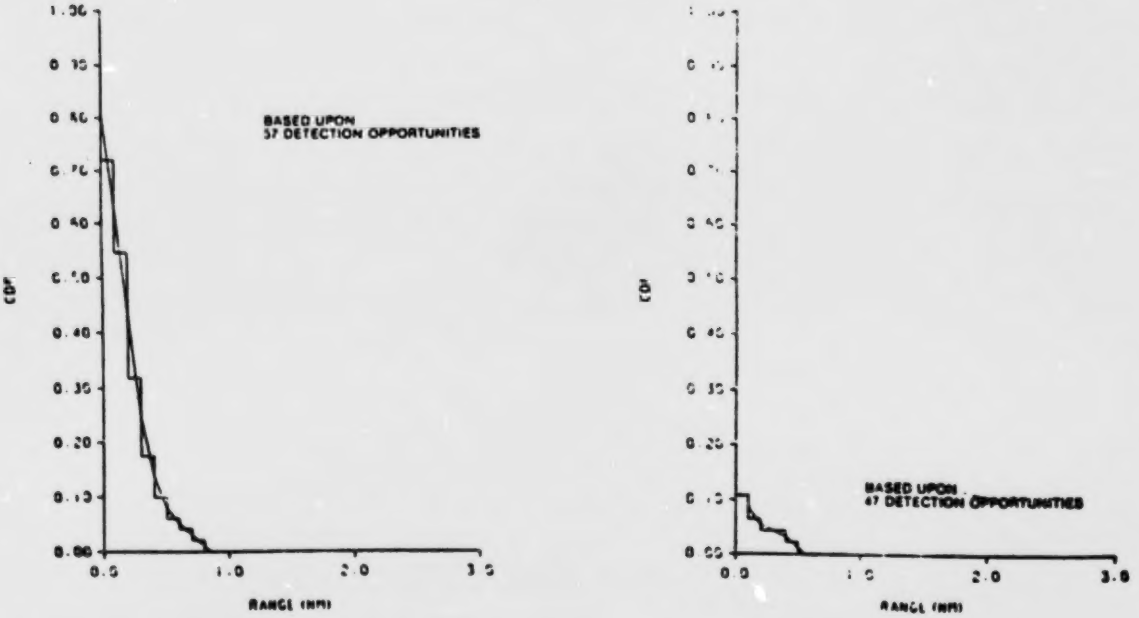
COMPARISON OF REAL-TIME AND POST-ANALYSIS FLIR DETECTION PERFORMANCE
(Nash et al, 1982)

TARGET TYPE	RANGE OF SIGNIFICANT WAVE HEIGHT (ft)	MEAN SIGNIFICANT WAVE HEIGHT (ft)	REAL TIME		POST-ANALYSIS		NUMBER OF OPPORTUNITIES
			PERCENT OF TARGETS DETECTED (number detected)	MEAN DETECTION RANGE (nm)	PERCENT OF TARGETS DETECTED (number detected)	MEAN DETECTION RANGE (nm)	
BOATS AND RAFTS	≤2	0.16	77 (24)	1.04	84 (26)	1.38	31
	>2	2.89	57 (13)	0.51	65 (15)	0.57	23
PIWs	≤2	1.08	74 (77)	0.25	75 (78)	0.25	104
	>2	2.78	11 (1)	0.10	11 (1)	0.10	9



CDP Versus Range for FLIR Searching for Small Boats and Life Rafts at 1000-Foot Altitude (Seas ≤2 feet)

CDP Versus Range for FLIR Searching for Small Boats and Life Rafts at Altitudes from 200 to 1500 Feet (Seas >2 feet)



CDP Versus Range for FLIR Searching for PIWs at Altitudes from 200 to 500 Feet (Seas ≤ feet, black-hot polarity)

CDP Versus Range for FLIR Searching for PIWs at Altitudes from 200 to 500 Feet (Seas >2 feet)

FIGURE 3.18 CUMULATIVE DETECTION PROBABILITY DATA FOR FLIR SYSTEMS FOR SMALL BOATS, LIFE RAFTS AND PIWs

(Hover et al, 1982)

A report by Lozinski and Corriveau (1984) discussed a FLIR performance model that can be used with hand-held calculators. The report discussed a fast, reliable FLIR performance model for use in the Canadian Forces. Advance knowledge that FLIRs can acquire data on a given target under given conditions allows the FLIR operator to select the search parameters that would result in optimum search efficiency or determine if FLIR should not be used because of expected poor performance. The program reads 18 inputs and plots the probability of detecting, resolving, or identifying a target as a function of its range from the aircraft. The following are the system inputs:

(i) System inputs:
  - horizontal wide field of view.
  - vertical wide field of view.
  - ratio wide over narrow field of view.
  - temperature factor.
  - frequency factor.
  - degradation of the MTF due to jitter.
  - temperature factor when going from wide to narrow field of view.
  - spectral bandwidth.

(ii) Aircraft inputs:
  - aircraft speed.
  - aircraft height.
  - scanning speed (search).
  - maximum scan angle (search).
  - depression angle (search).

(iii) Target inputs:
  - target height (or code).
  - target temperature differential (≥ 0).

(iv) Atmospheric inputs:
  - air temperature.
  - relative humidity.
  - visibility range.
  - aerosol flag = 1 - continental.
    2 - maritime.
    3 - rain.
    4 - snow.

The model has been developed so that some input parameters can be modified to check their effects on FLIR performance.

3.1.2.3 Vertical-Looking Scanning Systems

3.1.2.3.1 Literature Review

Scanning systems, commonly referred to as line scanners, are used extensively for a variety of applications. These include geology and geothermal mapping, forest fire mapping, water resources and pollution. Tests have been carried out over land for search and rescue but the literature search carried out for this study found only one reference on small object detection, and it was concerned with a freshwater background. This report (Anderson, 1978) identified some previous work by the U.S.C.G and the U.S. Army Electronics Command, Night Vision Laboratories in the late 1960s and early 1970s, but these reports were not generally distributed. Anderson reports that the early U.S.C.G. results were generally disappointing for the detection of small boats. The U.S. Army report as discussed by Anderson was concerned with LLLTV, FLIRs, another unidentified thermal imagery device and a search light. It was reported in Anderson that detection of PIWs was very difficult, although FLIR showed some promise. Anderson's study was concerned with the test of an infrared line scanner that was mounted in a Mohawk aircraft. Targets were scanned from altitudes of 500', 1000', 1500' and 2000'. The study showed that the infrared scanner had sufficient resolving power to identify the thermal signature of small boats and PIWs under controlled conditions. Under simulated search conditions, detection was also obtained. The study concluded that small boats of wood and fibreglass, and individual swimmers could be detected during both day and night, but that environmental conditions had been optimum.

3.1.2.3.2 Sensor Description

Scanning systems operate over the whole range of electromagnetic spectrum from the ultraviolet through the visible to the infrared. The Anderson (1978) study was concerned with an infrared system. A scanner that looks at the whole spectrum is called a 'multi-spectral scanner' (MSS). In reality, all scanners are variations of the MSS system. The literature is extensive and the major systems are summarized in FGBAL (1984). The systems basically consist of collector optics, scanning system, electrical recording and signal conversion mechanism, and various types of output devices. The major drawback is the lack of a real-time viewing device, although such devices can be constructed as demonstrated by the U.S.C.G. AOSS system. Tables 3.17 and 3.18 give some examples of commercially available specifications.

3.1.2.3.3 Probability of Detection

No studies concerning the POD of small objects on an ocean background were identified or located. As the systems search both the visual and infrared regions, the assumption can be made that similar detection probabilities would occur as with FLIR, LLLTV and human observers. Post analysis would have increased POD over real time observation. POD could probably be determined using similar methodologies.

3.1.2.4 Other Sensors

Two other sensor systems are mentioned because of their potential use; the first being the laser group, and the second, cameras.

3.1.2.4.1 Lasers

Lasers can be divided into laser range finders and lidars. Laser range finders have been used in conjunction with FLIR/LLLTV/active gated television sensors to measure the range of a target. They are thus not detection sensor systems. Lidars have been developed to measure through the water column. Success has been noted with up to 15 m water penetration. They are basically hydrographic sensors and developments in scanning lidars are now commencing. They could have possible use in identifying submerged targets such as a capsized boat that does not have enough buoyancy to float

TABLE 3.17

EXAMPLES OF SOME COMMERCIALLY AVAILABLE AIRBORNE INFRARED SCANNERS
(Bercha, 1984)

MANUFACTURER	SCANNER MODEL	METHOD OF SCANNING	SCAN TIMES/ SEC	SCAN WIDTH (°)	RESOLU-TION ELEMENT (MRAD)	TYPE OF COLLECT-ING OPTICS	FOCAL LENGTH (CM)	F/NO.	EFFECTIVE COLLECTOR AREA (cm^3)	METHOD OF RECORDING	V/H MAX	NE ΔT °K	WEIGHT	POWER	TYPE OF DETECTOR AVAILABLE
Texas Instruments	RS-310	4-sided Prism	200	90	1.5	Reflective	15	2.1	40.5	Film	0.3		96.5	dc:28V 9 amp	S-13 PM Silicon
TBM Hadar	Siddeley			12	1.5					Film	0.75	0.5	25	dc:28V 6 amp	Hg:CD:Te
Daedalus	DEI-100	Double-faced 45° mirror	120	120	2.5	Newtonian	15	1.2	45	Tape re-cording Film optional	0.3	0.3	65	dc:28V 5 amp	PM in:Sb Pb:Sn:Te
Daedalus	DS-1200	45° mirror	80	77	2.5	Newtonian	15	1.2	40.7	Tape re-cording Film optional	0.2	0.3-0.2	85	dc:28V 5 amp	B PM in:Sb Pb:Sn:Te
HRB Singer	Recono-fax VI	Double-faced 45° mirror	370	120 or 140	2 or 3	Newtonian	15	1.8	21.0		0.75-4.1	0.5-0.7	75	ac:3 phase 115V 400Hz surge, 1.5 amp steady	Ge:Hg in:Sb
HRB Singer	Recono-fax XIIIA	4-sided Prism	800	120	1 & 2mr (in same dewar)	Reflective	10	1.5	35	Film	1.6 sec/rad	0.3 @ 1mr 0.2 @ 2mr	135	28V DC @ 4.3 amps, 115VAC 400 Hz, 3 ph. 400 Watts	Hg:Cd:Te
Bendix T/M	LN-3	45° Prism	100	120	2.5	Dall-Kirkham	30	4	45.5	Film Tape Recorder Optional	0.25	0.3-0.2	55	dc:28V 5 amp	S-11 PM S-13 PM in:Sb Hg:Cd:Te

TABLE 3.18

EXAMPLES OF SOME COMMERCIALLY AVAILABLE MULTISPECTRAL SCANNERS

(Bercha, 1984)

MANUFACTURER	SCANNER MODEL	V/H MAX	METHOD OF SCANNING	SCAN LINES/SECOND	SCAN WIDTH DEGREES	RESOLUTION IFOV MRAD	TYPE OF COLLECTING OPTICS	FOCAL LENGTH & F/NO.	DIAMETER OF APERTURE	EFFECTIVE APERTURE AREA	ROLL COMPENSATION	CALIBRATION IN FLIGHT	METHOD OF RECORDING	METHOD OF SPECTRAL SEPARATION	TOTAL WEIGHT (LESS RECORDER)	POWER	SPECTRAL BANDS (μm)
Bendix Corp. Aerospace Systems Division	Multispectral Data System	0.18	Single 45° mirror	9.2-90	80	2.0	Dall-Kirkham	1,142 mm f/5.0	229 mm	38,100mm^2	Signal ± 8°	Blackbody, Q-H Lamp, Sky ref.	14 track Digital magnetic tape	Diffraction Grating	1,273 kg (2,800 lbs)	1,155 W 28VDC 10.2 KVA 115V	24 bands range 0.34-13.0
Daedalus Enterprises	Daedalus Spectrometer	0.2	Single 45° mirror	80	77	2.5	Paraboloidal Newtonian	152 mm f/2	127 mm	4,560mm^2	Signal ±10°	Q-H Lamp	7 track magnetic tape	Prism	54.3 kg (120 lbs)	132 W 28 VDC	19 bands range 0.38-1.10
Actron Ind., Inc.	HRB-564X	0.1	Conical	50	51.3	2	Cassegrain		150 mm		No stabilized mount (optional)	Lamp	Magnetic tape	Prism/Beam splitter	79 kg (175 lbs)	280 W 28 VDC	5 bands range 0.5-12.6
Texas Instruments	RS-14	0.2	4-sided mirror		80	10.3	Dall-Kirkham	254 mm f/3.7		3,740mm^2	Signal ± 8°	Blackbodies Q-H Lamp	CRT with film	Dichroic	120 kg (264 lbs)	154 W 28VDC 876 VA 115 VDC	7 bands (only 2 can be used at one time)

on the surface. Laser fluorosensors could be used to detect oil slicks. Table 3.19 gives details on commercially available laser systems.

3.1.2.4.2 Cameras

Cameras are devices that simulate the human eye. They can thus be used to replace the eye, but data can only be used for post-flight analysis. Their value is really in recording a permanent record of a search and rescue scene.

3.2 All-Weather Detection

For the purposes of this study, all-weather detection includes the radar sensing systems that can, with some exceptions, operate under day/night all-weather conditions. These systems have both real-time and recorded outputs. They are somewhat sophisticated and require electronic support, but tend to have greater lateral range capablity than the visual detection sensors. They include: side-looking airborne radars (SLARs), forward-looking airborne radars (FLARs) and passive microwave radars.

3.2.1 Side-Looking Airborne Radar (SLAR)

3.2.1.1 Literature Review

The U.S.C.G. has been conducting real-aperture side-looking airborne radar search and rescue detection studies since 1978. A series of reports discusses how the Airborne Oil Surveillance System (AOSS) or the SLAR/Radar Image Processor (SLAR/RIP) configurations of the AN/APS-94D SLAR detected life rafts, small boats, and 45' to 95' vessels. Edwards et al. (1980c) discusses the first U.S.C.G. trials. The preliminary trials were conducted to determine the influence that certain environmental and controllable parameters have on SLAR detection for the types of targets assessed. The following parameters were studied:

TABLE 3.19

EXAMPLES OF SOME LASER DEVICES
(Bercha, 1984)

ORGANIZATION (VENDOR)	TYPE	TRANSMITTER						RECEIVER					RECORDING MEDIUM	WEIGHT (kg)	POWER
		LASER	WAVELENGTH	PULSE LENGTH	PULSE ENERGY	BEAM DIVERGENCE	REPETITION RATE	TELESCOPE	CLEAR APERTURE	FOV	INTENSIFIER ON-GATE PERIOD	SPECTRAL RANGE (nm)			
CCRS MK III	Laser fluorosensor	Nitrogen gas	337 nm	3 ns (FWHM)	1mJ/pulse	3mrad x 1mrad	100 Hz	f/3.1 Dall-Kirkham	.0232 m^2	3mrad x 1mrad	70 ns	377-689	Computer compatible tape (CCT)	267	28VDC.20.5A 110V, 50Hz, 9A
U.S. Dept. of Navy	1.06 micron CW Laser radar system	CW Nd; YAG	1.06 micron		Modulated output power 0.2 to 1 watt	5mrad		Reflective Cassegrain	20.5 sq cm	4-24mrad	CW		Magnetic tape		
Spectra physics model 164	underwater LIDAR	argon-ion	488 nm	10 nanoseconds	Peak power up to 75 watts		10^7 Hz	Newtonian	diameter of telescope 20 cm			450-520			
Avco Everett Research Lab.	Raman system	Flash lamp pumped dye	4400 Å	10 ns	Peak power 10^5 watts				aperture diameter 0.3 m	10mrad					
[illegible]	Fluorosensor	Nitrogen/neon	3371.1Å 5400.56Å	9 ns (FWHM) 3 ns (FWHM)	Peak power 140 kw 20 kw	13.5 mrad v 3.6 mrad	1 to 100 pps (continuously variable) or single shot	Newtonian	diameter 20.3 cm				Magnetic tape		
Environment Canada	Fluorometer	Helium Cadmium	442 nm & 325 nm			1mrad		Schmidt Cassegrain			CW			100	60 Hz, 120VA
[illegible] & [illegible] Inc.	Fluorosensor	Nitrogen	337 nm	10 nsec	1mJ/pulse	20 x 2mrad	100 pulses per sec	f/1 Cassegrain	diameter 23 cm			450-500nm 540 for bathymetry	Magnetic tape		
NASA	Laser bathymeter	[illegible] frequency doubled Nd:YAG	540 nm 532 nm	5 to 7 nsec	Peak power 2 Mw 12 mJ 2 Mw 10 mJ	2 x 5 mrad	10-200 pps 10- 20 pps	f/1 Cassegrain	diameter 28 cm				Movie camera or magnetic tape	90	

- (a) Environment Related:
    - (i) Wind speed.
    - (ii) Swell height.
    - (iii) Relative humidity.
    - (iv) Precipitation.
    - (v) Image background.
    - (vi) Visibility.
- (b) Controllable:
    - (i) Target size and composition.
    - (ii) Antenna polarization.
    - (iii) Gain.
    - (iv) Altitude.
    - (v) Lateral range.

From the preliminary assessment, it was found that the following parameters influenced SLAR detection of search and rescue targets:

- (a) Environment Related:
    - (i) Wind speed.
    - (ii) Precipitation.
    - (iii) Image background.
- (b) Controllable:
    - (i) Target size and composition.
    - (ii) Antenna polarization.
    - (iii) Altitude.
    - (iv) Lateral range.

Wind speed was found to be the most significant, as target detection degraded dramatically as wind speed increased. The increase in wind speed resulted in increased sea state, which caused the image background to vary. Other reasons for background variation included precipitation, gain selection and altitude. Precipitation contributes to poor image quality and makes the resolution of small objects difficult. Target size and composition appeared to be the most significant parameter effects in determining detection performance. Larger targets were detected almost all the time; smaller boat detection is influenced by the composition of the boats; and small corner reflectors did not appear to enhance the detectability of the rafts. Horizontally, polarized antennas gave better detection performance with hard targets. It appeared that optimum search altitudes existed for different target types and a blind zone existed below the aircraft, which was partially altitude dependent. No detection could occur in the blind zone which could extend out as far as 2 nm. A maximum detection range of 18 nm was found for the SLAR/RIP as a generalized preliminary result. It was found that the data base of the study was not extensive enough to develop PODs for SLAR searches.

Further results were reported by Osmer et al. (1981a). This report added 1980 results to the above-described data base. The results were basically unchanged with the exception that it was stated that the SLAR/RIP could detect targets at larger scales than the AOSS.

Osmer et al (1981b) continued reporting the U.S.C.G. series of studies. This study reported that the significant detection parameters were as follows:

1. Environment-Related
   - (a) Swell height.
   - (b) Wind speed.
   - (c) Visibility.
   - (d) Precipitation.
   - (e) Relative humidity.
2. Controllable
   - (a) Target size and composition.
   - (b) Lateral range.
   - (c) Altitude.
   - (d) Gain (SLAR/RIP only).

Osmer et al (1982) continued the analysis of all collected data. This report contained POD predictions and sweep width calculations. It basically continued the parameter analysis carried out in the earlier reports.

3.2.1.2 System Description

The AOSS SLAR has an 8' vertically-polarized antenna on the right side and a 16' horizontally polarized antenna on the left side. The vertically-polarized antenna was effective in detecting soft targets such as changes in sea return, while the horizontally polarized antenna was more efficient for detecting hard targets such as ships and icebergs. The SLAR/RIP system employs a single, 16' long, horizontally polarized antenna and is equipped with a sophisticated image analysis and storage/retrieval system. The SLAR computer compensates for signal attenuation, aircraft speed and altitude, and annotates the video display with date, time, position, speed, altitude and range mark information. Film records can be made inflight for post-experiment analysis. Both SLARs are versions of the same system design.

The AN/APS-94D radar combines an onboard computer system, video monitors and photographic recorders to compose a sensor system. SLARs operate by microwave echo ranging using the forward motion of the aircraft to advance the display. Combined with a long antenna, this method provides for high quality resolution. The SLAR system performs yaw and slant range corrections. In addition to the photographic format, the video monitor enhances the radar signals.

The two radar systems used are distinctly different, but the operating ranges and navigational capabilities of the aircraft are similar. Simultaneous testing could not be carried out with the two aircraft.

Because of the angle through which the signal is transmitted, a blind zone roughly equal to the aircraft altitude extends on each side of the aircraft. Other aircraft with similar systems have different antenna looks and this blind zone is called a 'delay space' and can be set at the radar. The blind zone on U.S.C.G. aircraft can be reduced by flying at lower altitudes (Figure 3.19), but this will increase the amount of shadow produced by taller objects and increase the amount of sea return near the edge of the blind zone (Figure 3.20). Shadow length can by found using:

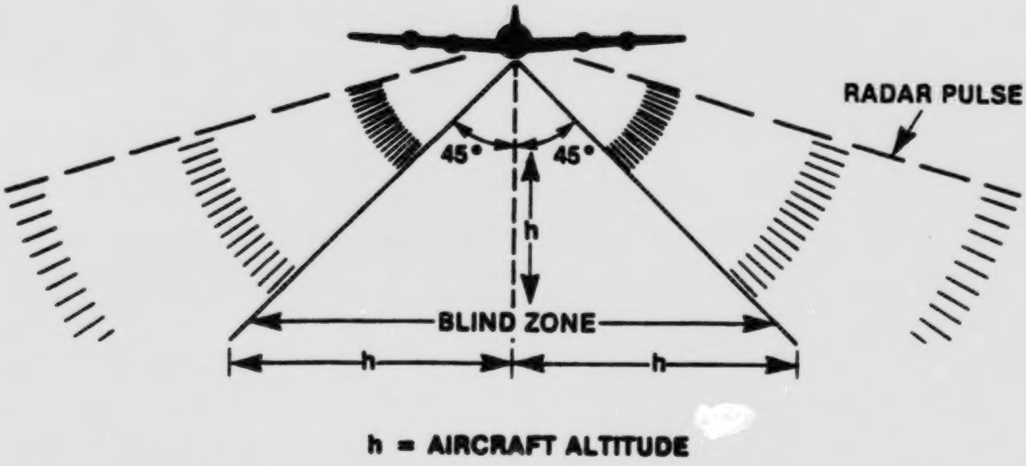

RADAR PULSE
45°
45°
h
BLIND ZONE
h
h
h = AIRCRAFT ALTITUDE

FIGURE 3.19 BLIND ZONE IN SLAR COVERAGE
(U.S.C.G.)

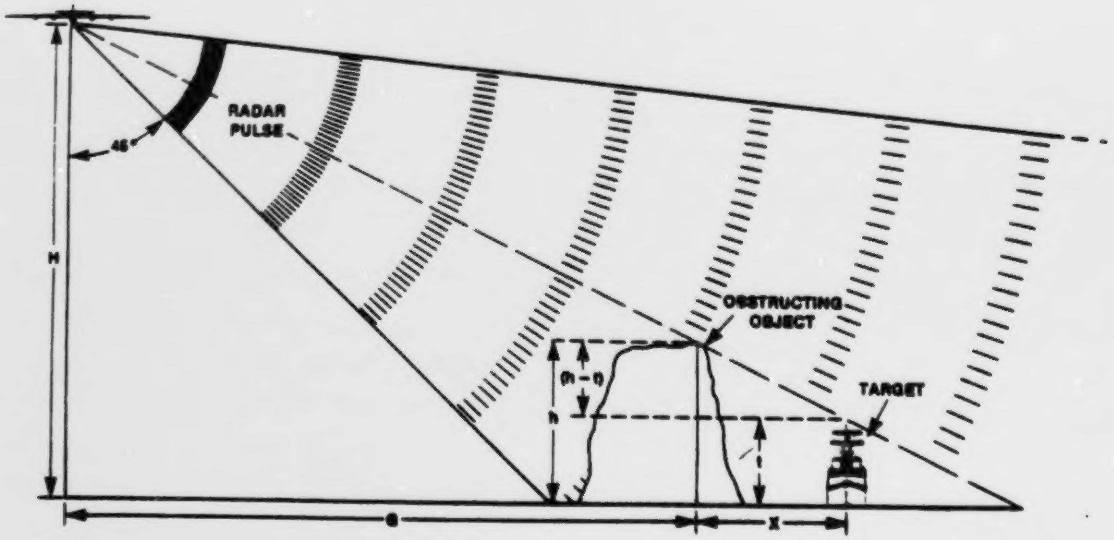

RADAR PULSE
45°
H
OBSTRUCTING OBJECT
(h – t)
h
t
TARGET
s
X

FIGURE 3.20 GEOMETRY INVOLVED WITH SHADOWING EFFECT (U.S.C.G.)

$$X = (h - t)\, G/(H - h)$$

where X = length of shadow zone created by obstructing object,
G = obstructing object range from flight path,
h = obstructing object height,
t = target height,
H = aircraft altitude.

This equation yields the length of the shadow zone that an obstructing object will create for a target of given size. Resolution, the detection and differentiation between individual target provided one does not shadow the other, in the cross-track direction is dependent on the microwave pulse length and remains constant as range increases (30 m for the U.S.C.G. SLAR). Resolution in the along-track direction depends on beamwidth and deteriorates at a rate of 9 m/km, commencing from an initial resolution of 9 m at 1 km (Edwards et al, 1980c).

Table 3.20 gives examples and general specifications for example airborne radar systems.

3.2.1.3 Probability of Detection

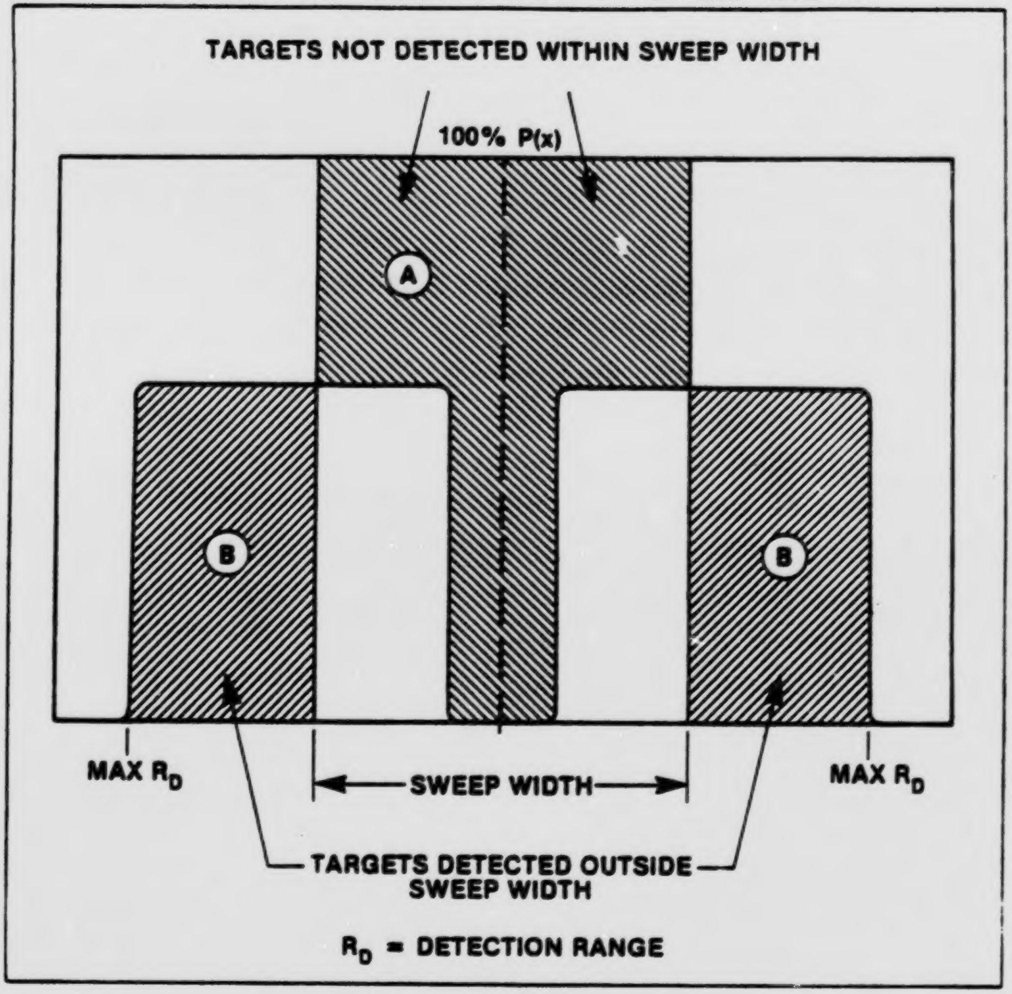
Although the sweep width is defined mathematically, as for human observation, and the definition for lateral range remains the same; the graphic representation is different for SLAR (Figure 3.21). Electronic sensors perform differently than the human eye or electro--optical sensors over lateral ranges in that they obey a definite detection law type function. That is, they have a fairly uniform P(x) out to their maximum range and detect no targets beyond that range. Therefore, targets that have strong signal reflection and are not affected by shadowing have a P(x) which approaches 1.0, while targets that have weak signal reflection and are subject to shadowing have a low P(x). The delay space or blind zone results in a hole in the P(x) vs. lateral range curve. Using the search and rescue concept of sweep width, Figure 3.21 graphically presents the sweep width for SLAR. For visual searches, W is used to calculate C, which is then used to predict the cumulative probability of detection (POD) for a given search. This

TABLE 3.20

EXAMPLES OF SOME COMMERCIALLY AVAILABLE AIRBORNE RADARS
(Bercha, 1984)

ORGANIZATION OR MANUFACTURER	APERTURE	TYPE	FREQUENCY OR WAVE LENGTH (cm)(GHz)	TRANS-MITTER PEAK POWER	ANTENNA GAIN	ALONG TRACK BEAM WIDTH	DEPRES-SION ANGLE	MAXI-MUM RANGE	PULSE WIDTH	RESOLUTION		RECORDING	WEIGHT (kg)	POWER	POLARIZA-TION
										RANGE	AZIMUTH				
ERIM	syn-thetic	X-band L-band	9.350 (3.2 cm) 1.315 (22.8 cm)	1 Kw 5 Kw	28 db 16.5 db	1.1° 7°	0-90 0-90	24.1 km 24.1 km	3 μsec 2 μsec	1.5 m 2.3 m	2.1 m 2.1 m	film, single channel real time processor (optional)	1635 (total)	4.8 kVA	HH, VV, HV, VH
SLAR		X-band	3.5 GHz			Antenna 4.4°		5-15m				analog (FM) or digital			VV, HH, VH, HV
SLAR [illegible]-94		X-band		45 kw min		9° for vertical polarisation .45° for H polarisation		25-5 km swath cover-age	0.2±0.025 μ sec	100 ft 30 m	95.6 ft/n 30 m	TV monitor as rolling map display - 9" film			
Microwave Scatterometer		Ryan Model 720 slotted guide phased array	13.3 (2.25 cm)	2 Watts	38 db	3° (broadside)	120° (fore/aft)			.052 x (alti-tude (m))	.26X (ground speed (ms^{-1}))	instrumenta-tion tape recorder (analog)	Antenna 16 Electron-ics 11	110V 400Hz 2.8A 110V 60Hz .3A	HH, VV, VH, HV
Westinghouse	real	APD-7	8.6 mm					21 km		8 km	1.7 R km	real time dis-play & film	225	3170 W	HH
Motorola	real	APS-940	32 mm 56 mm					100km		30 km	1.7 R km 15 R km	real time dis-play & film	235	1940 W	HH, VV HH, VV
EMI	real	P391 and X-band	8.6 mm 32 mm					28 km 63 km		15 km 30 km	3.5 R km 16 R km	real time dis-play & film	195	900 W 800 W	HH HH
Erickson	real		32 mm	10 Kw	31 db			20 km	.5 μsec	75 km	7.5 X R km	real time dis-play & film			VV
Goodyear	syn-thetic	APQ-102	31 mm					37 km		15 km	15 km	film	232	2951 W	HH

A. GRAPHIC PRESENTATION OF SWEEP WIDTH


TARGETS NOT DETECTED WITHIN SWEEP WIDTH
100% P(x)
A
B
B
MAX R_D
MAX R_D
SWEEP WIDTH
TARGETS DETECTED OUTSIDE SWEEP WIDTH
R_D = DETECTION RANGE

B. PICTORIAL PRESENTATION OF SWEEP WIDTH

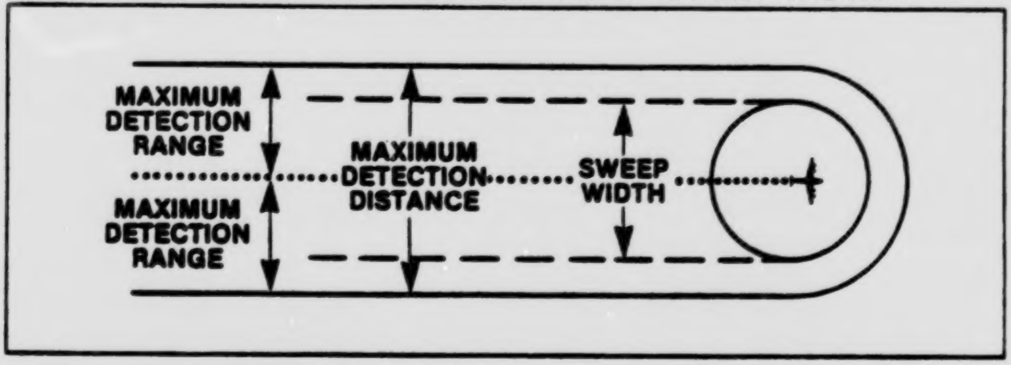

MAXIMUM DETECTION RANGE
MAXIMUM DETECTION RANGE
MAXIMUM DETECTION DISTANCE
SWEEP WIDTH

FIGURE 3.21 GRAPHIC AND PICTORIAL PRESENTATION OF SWEEP WIDTH FOR SLAR (Edwards et al, 1980c)

model uses the assumption that the instantaneous glimpse, POD, is inversely proportional to the cube of the range to the target. For SLAR this is not a valid assumption (Edwards et al, 1980c).

Edwards et al (1980c) provides the first data on target detection. AOSS detection had lateral ranges of less than 12 nm. The SLAR/RIP had lateral ranges of 1.3 to 35 nm. Figure 3.22 shows the AOSS data for small boats and Figure 3.23 shows POD vs. lateral range for horizontal and vertical antenna types and shows that horizontal polarization is better for hard targets. Table 3.21 shows the influence of the various parameters on AOSS detection of small boats. AOSS POD for life rafts is given in Figure 3.24 and the effects of wind speed on detection of life rafts can be seen in Table 3.22. SLAR/RIP POD is shown in Figure 3.25, which shows P(x) vs. lateral range for small boats and Table 3.23 shows the parameter influence for the same data. P(x) vs. lateral range for SLAR/RIP for life rafts is given in Figure 3.26 and Table 3.24 shows the parameter influence. In summary, Figures 3.27 and 3.28 show estimated P(x) vs. lateral range for medium and large targets, and small targets, respectively. No real conclusions were made concerning P(x) vs. lateral range and W at this point in the U.S.C.G. study. The results appeared to be similar to an earlier U.S.C.G. study by Powell (1968), although in that study an APS/94C SLAR was tested. The authors also made a comparison of SLAR with visual search methods (which is the U.S.C.G. standard for comparison). Figure 3.29 shows the comparison for small targets. The lateral range curves are much different in shape for the two search methods. Using the visual sweep width calculation the authors found:

$$W = \int_{-\infty}^{\infty} P(x)dx = 3.7 \text{ for visual detection.}$$

For SLAR the following mathematical expression was used:

$$W = 2\int_{X_{min}}^{X_{max}} P(x)dx = 2\overline{P}(x)(X_{max} - X_{min})$$

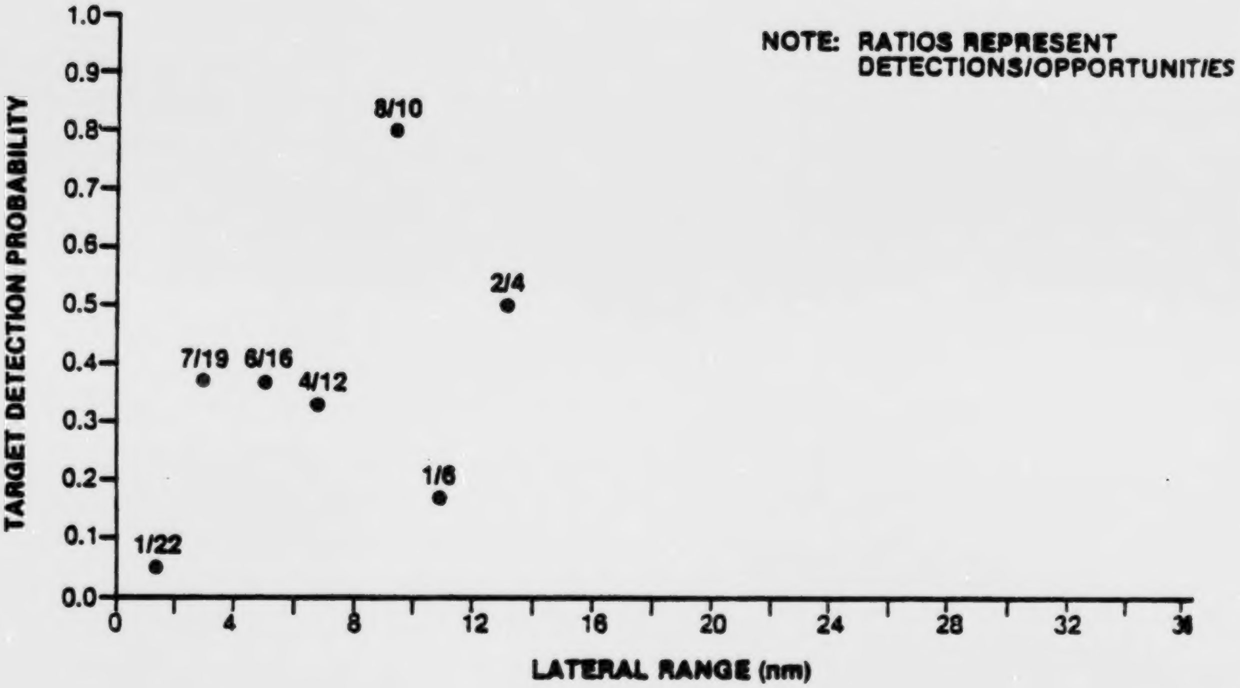


FIGURE 3.22 EMPIRICAL SUCCESS RATIOS VERSUS LATERAL RANGE FOR AOSS SLAR SEARCHING FOR SMALL BOATS (Edwards et al, 1980c)

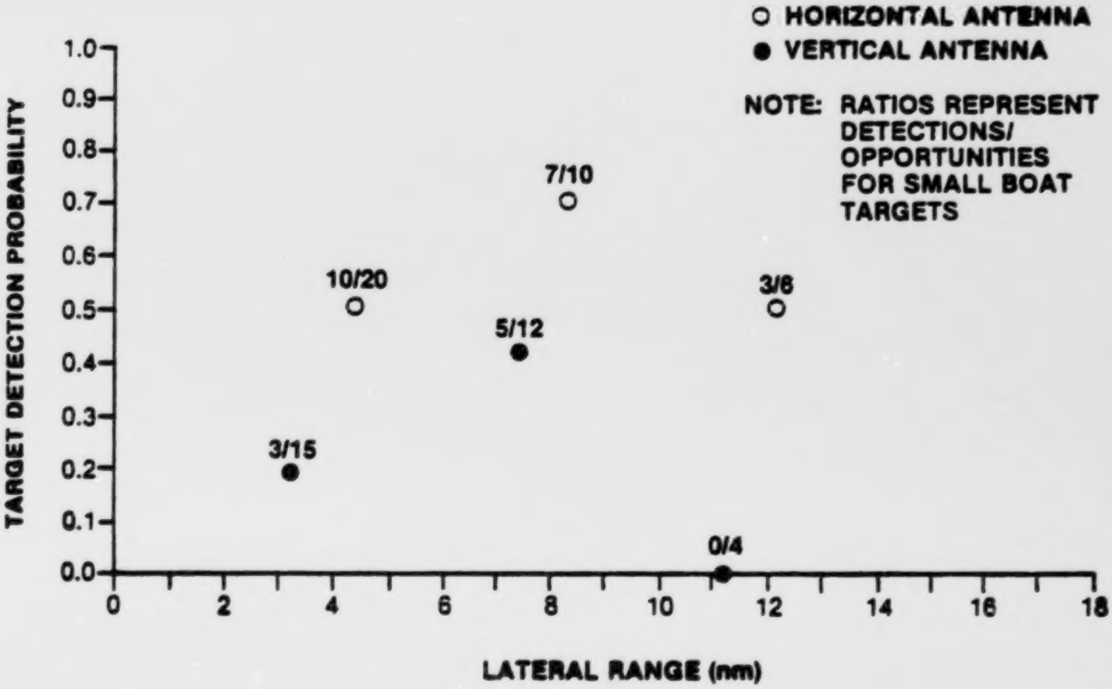


FIGURE 3.23 AOSS SLAR: HORIZONTAL VERSUS VERTICAL ANTENNA POLARIZATION
(lateral range $\geq$ 2 nm)
(Edwards et al, 1980c)

TABLE 3.21

INFLUENCE OF PARAMETERS OF INTEREST ON AOSS SLAR DETECTION OF SMALL BOATS

(Lateral Ranges $\geq$ 2 nm)

(Edwards et al, 1980c)

Variable of Interest	Detections/ Opportunities	Target Detection Probability	Average Conditions				Remarks
			Altitude (ft)	Wind Speed (knots)	Sea Height (ft)	Background (% scattered/ dark)	
Background							
Clear/light	23/38	.61	1866	6.5	1.9	0	
Scattered/dark	5/29	.17	1044	10.5	3.2	1.00	Higher wind speed and sea height characteristic of dark background
Wind Speed (knots)							
≤ 10	22/41	.54	1712	5.9	1.5	.24	
> 10 to 20	6/26	.23	1192	11.8	4.0	.73	Higher wind speed and sea height characteristic of dark background
Target Type							
19' - 21' fiberglass or aluminum w/full equipment and I/O motor	16/25	.64	1550	4.7	1.4	.23	
13' - 15' fiberglass w/o equipment	12/42	.29	1294	10.4	3.1	.67	P(x) for this target type may be lower partly due to differences in environmental conditions.

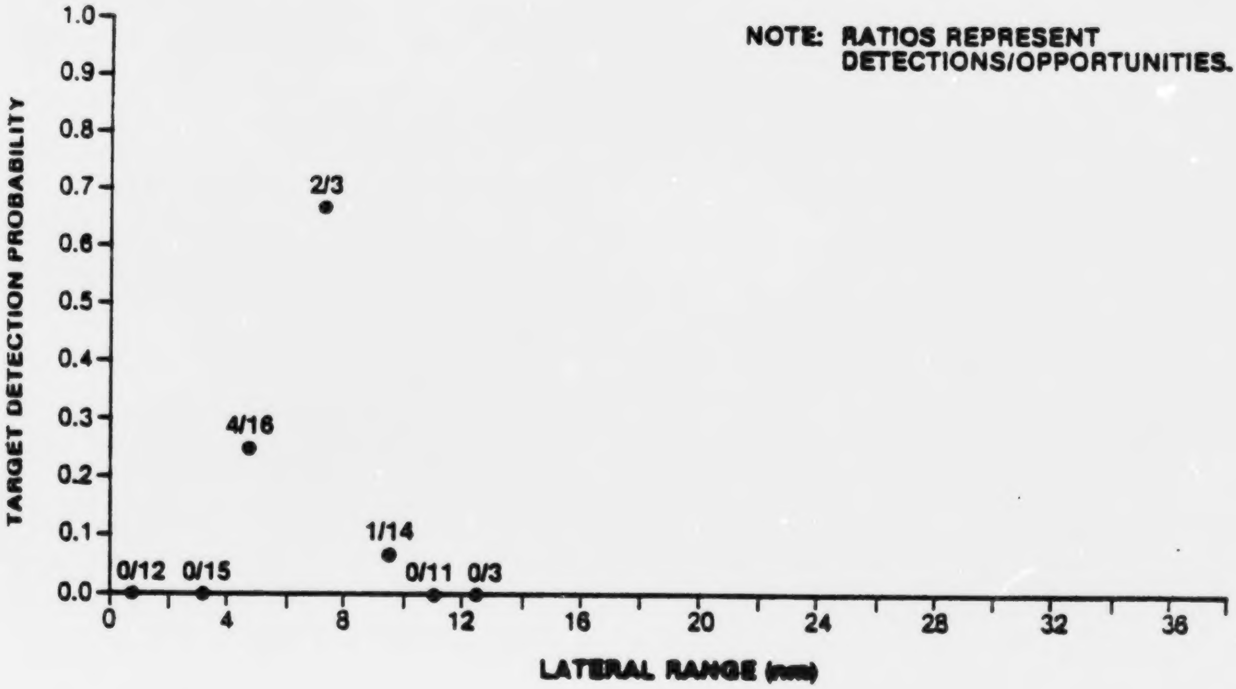


FIGURE 3.24 P(x) VERSUS LATERAL RANGE FOR AOSS SLAR SEARCHING FOR LIFE RAFTS (Edwards et al, 1980c)

TABLE 3.22

EFFECTS OF WIND SPEED ON AOSS SLAR DETECTION OF LIFE RAFTS

(Lateral Ranges $\geq$ 2 nm)
(Edwards et al, 1980c)

Wind Speed (knots)	Detections/ Opportunities	Target Detection Probability	Altitude (ft)	Sea Height (ft)	Background (% scattered/ dark)	Antenna Polarization (% vertical)
10	5/28	.18	3175	1.8	.57	.57
20	2/15	.13	2200	3.0	1.00	.60
30	0/20	0	1600	3.0	.85	.35

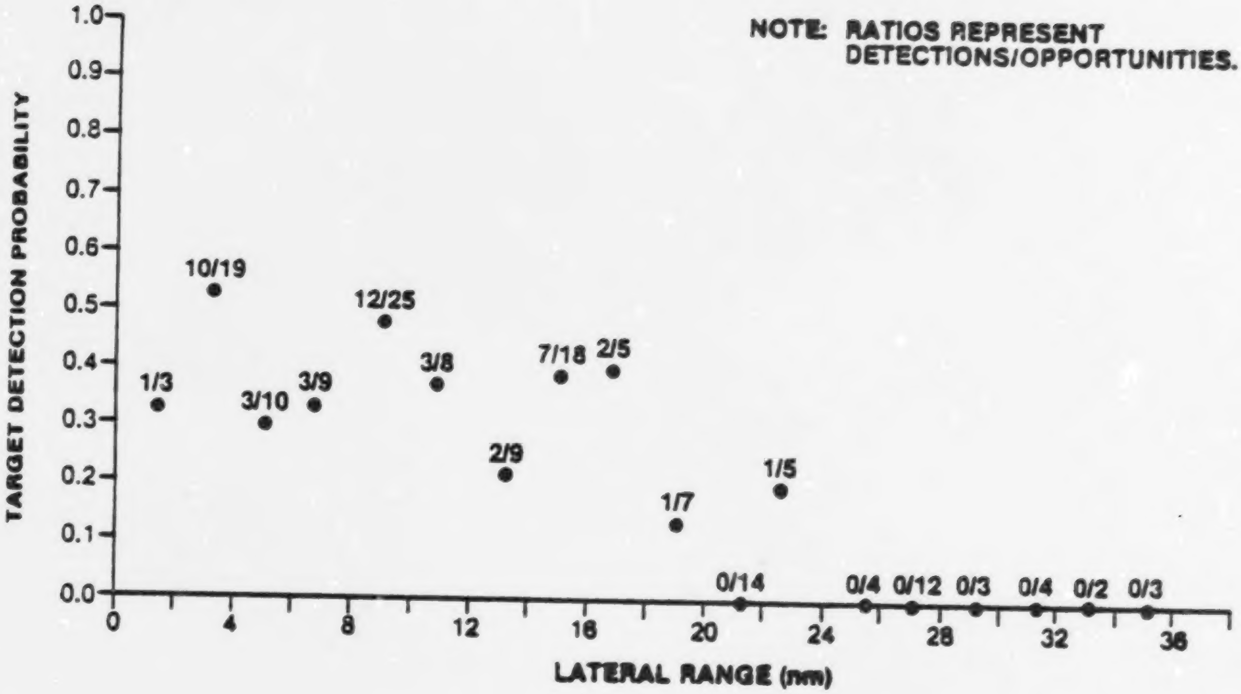


FIGURE 3.25 P(x) VERSUS LATERAL RANGE FOR SLAR/RIP SEARCH FOR SMALL BOATS (Edwards et al, 1980c)

TABLE 3.23

INFLUENCE OF PARAMETERS OF INTEREST ON SLAR/RIP DETECTION OF SMALL BOATS
(Lateral Ranges 2 - 18 nm)

(Edwards et al, 1980c)

VARIABLE OF INTEREST	DETECTIONS/ OPPORTUNITIES	TARGET DETECTION PROBABILITY	ALTITUDE (ft.)	WIND SPEED (knots)	SEA HEIGHT (ft.)	BACKGROUND (% Scattered/ dark)	PRECIPITATION (% when present)	ANTENNA GAIN (Setting)
Wind Speed (kts)								
≤ 10	37/72	.51	3389	7.0	2.6	.28	.07	4.7
≥ 10 to 20	5/31	.16	3258	15.9	2.7	.71	.45	3.8
Background								
clear/light	32/61	.52	3704	8.1	2.6	0.0	.08	4.7
scattered/dark	10/42	.24	2833	12.0	2.6	1.00	.33	4.0
Precipitation								
none	38/84	.45	3298	8.6	2.7	.33	0.0	4.4
present	4/19	.21	3579	14.4	2.1	.74	1.00	4.6
Altitude (ft.)								
2000	6/32	.19	2000	9.7	2.4	.53	.16	3.5
3000	20/37	.54	3000	10.3	2.5	.54	.16	4.5
5000	16/34	.47	5000	8.9	2.9	.15	.24	5.2
Target Type								
15' or 17' fiberglass w/ limited equip.	19/51	.37	3216	10.2	2.6	.39	.06	4.1
13' - 15' fiberglass shell	23/52	.44	3481	9.1	2.6	.42	.31	4.7

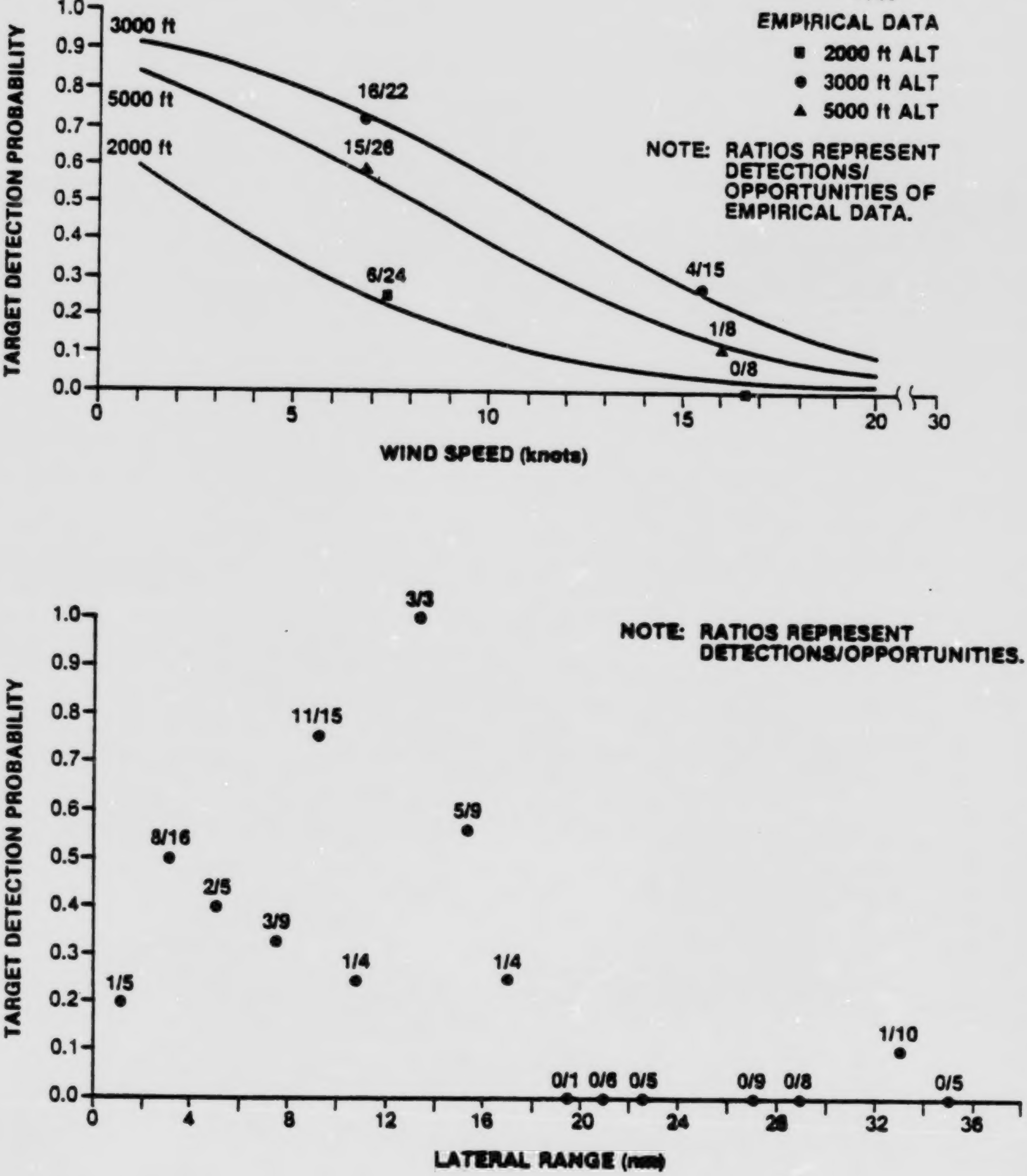


FIGURE 3.26 P(x) VERSUS LATERAL RANGE FOR SLAR/RIP DETECTION OF LIFE RAFTS (Edwards et al, 1980c)

TABLE 3.24

INFLUENCE OF PARAMETERS OF INTEREST ON SLAR/RIP DETECTION OF LIFE RAFTS
(Lateral Ranges 2 - 18 nm)
(Edwards et al, 1980c)

VARIABLE OF INTEREST	DETECTIONS/ OPPORTUNITIES	TARGET DETECTION PROBABILITY	ALTITUDE (ft.)	WIND SPEED (knots)	SEA HEIGHT (ft.)	BACKGROUND (% scattered/ dark)	ANTENNA GAIN (setting)
Wind Speed (knots)							
≤ 10	33/53	.62	3368	5.6	0.2	.25	5.0
≥ 10 to 20	1/12	.08	2000	15.3	2.8	.50	2.1
Background							
Clear/light	30/43	.70	3023	6.6	0.5	0.0	4.4
Scattered/dark	4/22	.18	3295	8.9	1.1	1.00	4.6
Raft Type							
Canopied w/ reflector	10/16	.62	3531	4.9	0.1	.19	4.9
Canopied w/o reflector	5/22	.23	2727	11.2	1.7	.50	3.6
w/o canopy or reflector	19/27	.70	3185	5.6	0.2	.30	4.9
Altitude							
1000	0/3	0.0	1000	14.0	2.0	.33	1.0
2000	9/21	.43	2000	8.3	.86	.52	3.8
3000	21/30	.73	3000	6.5	.47	.10	4.6
5000	3/6	.50	5000	5.0	.33	.17	6.0
7500	0/5	0.0	7500	7.0	1.0	.60	7.0

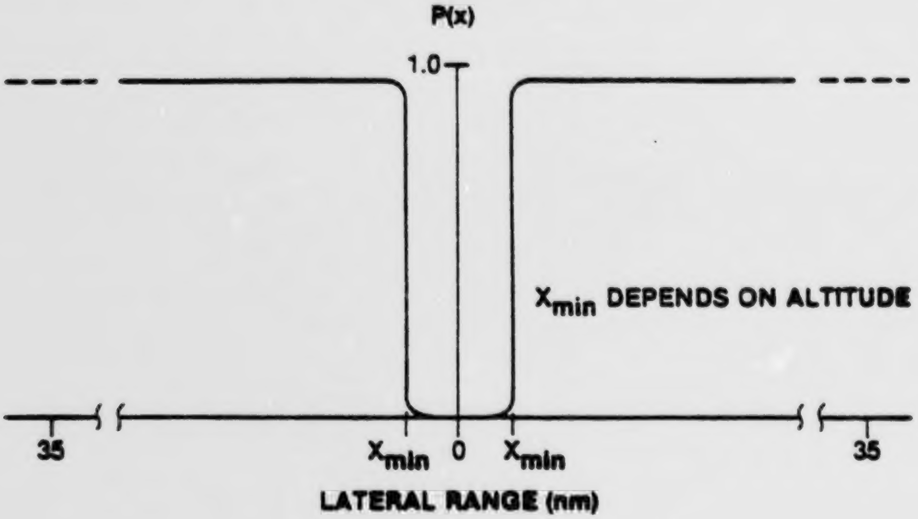


FIGURE 3.27 ESTIMATED SLAR P(x) VERSUS LATERAL RANGE CURVE FOR MEDIUM AND LARGE TARGETS

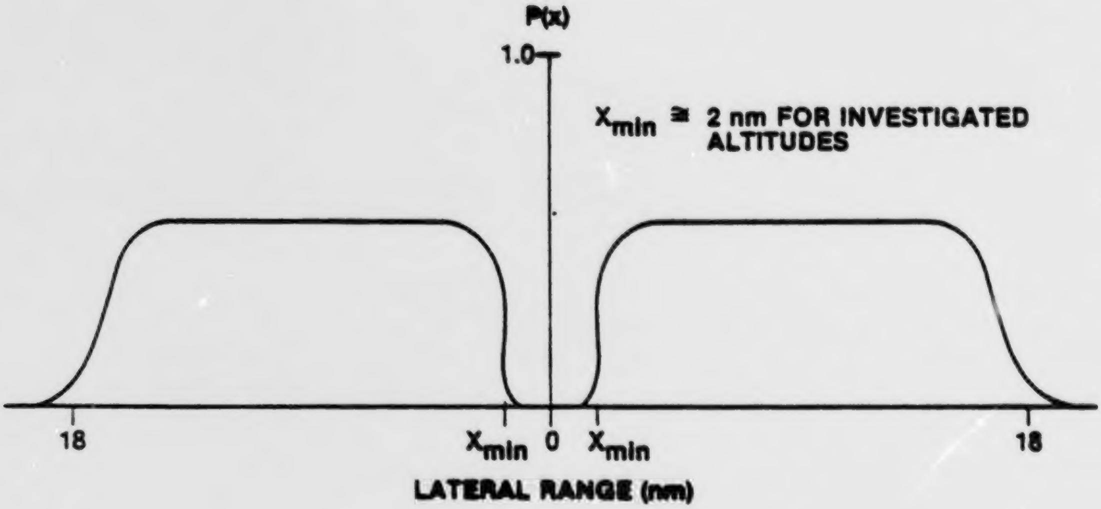


FIGURE 3.28 ESTIMATED SLAR P(x) VERSUS LATERAL RANGE CURVE FOR SMALL TARGETS (Edwards et al, 1980c)

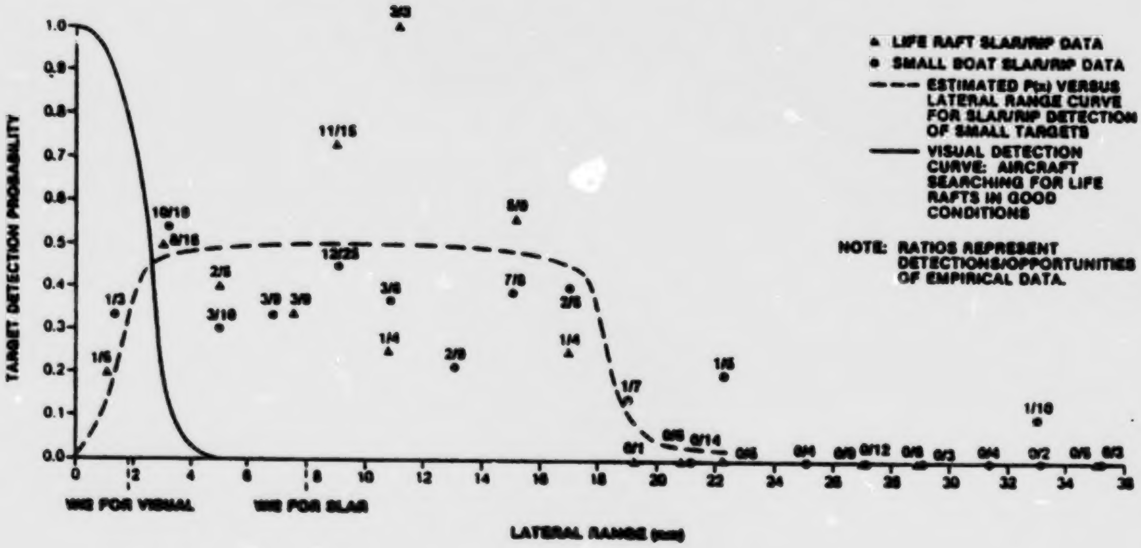


FIGURE 3.29 COMPARISON OF SLAR/RIP AND VISUAL DETECTION PROBABILITY OVER LATERAL RANGE FOR SMALL TARGETS
(Edwards et al, 1980c)

where X_{min} = approximate minimum lateral range for SLAR detection of small targets (about 2 nm).

X_{max} = approximate maximum lateral range for SLAR detection of small targets (about 18 nm).

$\bar{P}(x)$ = mean value of P(x) over the interval from X_{min} to X_{max} (approximately 0.5 in this example).

Using this expression, W = 16 nm. Thus, the one half sweep widths are 1.85 nm for visual and 8 nm for SLAR.

Interpretation of search performance differs for each sensor. The visual method uses W to determine cumulative POD. This is not valid for SLAR; Figure 3.30 illustrates a comparison. For visual detection, if a parallel search pattern was flown with track spacing (S) equal to W, the lateral range curve would overlap itself on adjacent legs to provide fairly uniform coverage, POD approaches 90%. For a SLAR search where S = W, area coverage is not as uniform, and POD is 0.5 for targets located near the flight track (effect of blind zone) and 0.75 for targets located between flight tracks. S for SLAR is 4 x S for visual, therefore, less time is required per search. Thus, POD could increase by increasing coverage of the same area.

Osmer et al (1981b) continued the analysis. Table 3.25 shows the range of parameters investigated and Table 3.26 the sweep widths and optimum altitudes derived from the study results. At the time of writing of this report, there were 1216 detection opportunities for the AOSS system and 1599 for the SLAR/RIP. Table 3.27 summarizes the detection opportunities. The authors used the visual detection LOGODDS regression model to find the best qualitative relationship between the multiple independent variables (x_i) tested and $P(x_i)$. For visual data, the monotonic stimulus-response (S-R) behavior is well suited (Section 3.1.1.3). The lateral range curves for the SLAR data are not monotonic, they are unimodal (Figure 3.31), but the LOGODDS routines were used as they would represent an upper bound for detection performance. For medium and large targets, Figure 3.32 was constructed. The figure shows data for both AOSS and SLAR/RIP. For AOSS, there was a

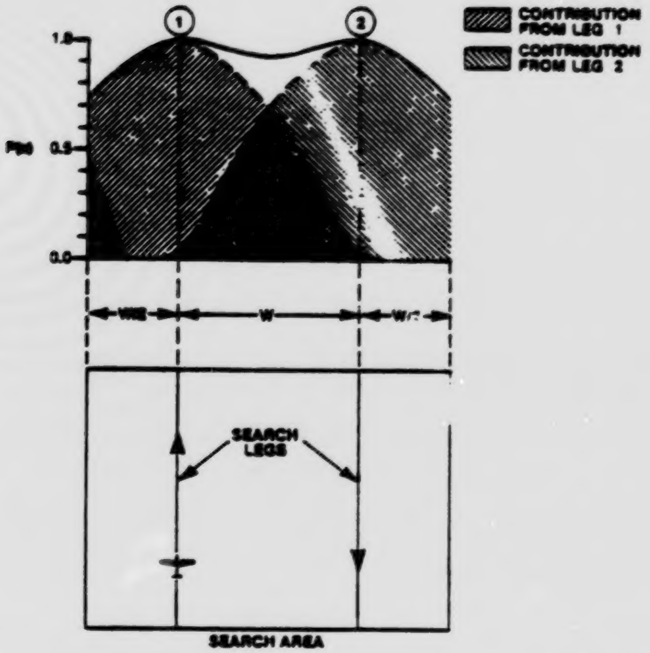

CONTRIBUTION FROM LEG 1
CONTRIBUTION FROM LEG 2
①
②
1.0
0.5
0.0
P(x)
W/2
W
W/2
SEARCH LEGS
SEARCH AREA

FIGURE 3.30a EXAMPLE OF SEARCH AREA COVERAGE FOR VISUAL SEARCH

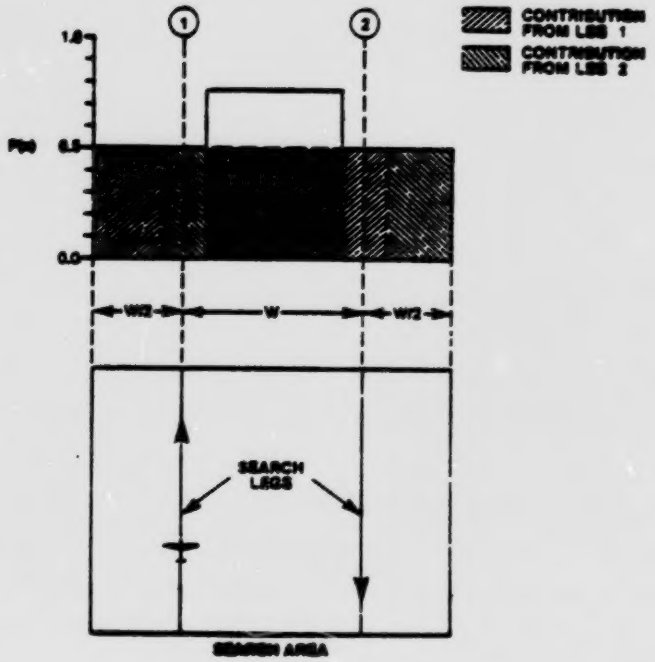

CONTRIBUTION FROM LEG 1
CONTRIBUTION FROM LEG 2
①
②
1.0
0.5
0.0
P(x)
W/2
W
W/2
SEARCH LEGS
SEARCH AREA

FIGURE 3.30b EXAMPLE OF SEARCH AREA COVERAGE FOR SLAR
(Edwards et al, 1980c)

TABLE 3.25

RANGE OF PARAMETERS INVESTIGATION DURING SLAR EXPERIMENTS

(Osmer et al, 1981b)

SLAR Type	Target Type	Lateral Range (nm)	Altitude (ft)	Visibility (nm)	Wind Speed (knots)	Swell Height (ft)	Antenna Polarization	Image Background	Gain[1]	Precipitation	Relative Humidity (%)	Wave Direction[1] (relative to beam)
AOSS SLAR	Life rafts	0-27	500-5500	1-15	3-30	0.5-3	Vertical and horizontal	Clear/light Scattered/dark	N/A	Clear Fog Rain	59-100	Perpendicular Parallel
	Small boats	0-27	1000-5500	1-15	3-17	0.5-4	Vertical and horizontal	Clear/light Scattered/dark	N/A	Clear Rain	55-100	Perpendicular Parallel
	41'-95' Coast Guard vessels	0-27	1000-5000	1-15	3-12	0.5-4	Vertical and horizontal	Clear/light Scattered/dark	N/A	None	55-100	Perpendicular Parallel
SLAR/RIP	Life rafts	0-45	1000-7500	1.5-15	4-17	0-3	Horizontal	Clear/light Scattered/dark	1-7	None	54-94	Perpendicular Parallel
	Small boats	0-45	2000-5000	1.5-15	4-17	0-3	Horizontal	Clear/light Scattered/dark	2-7	Clear Fog Rain	59-100	Perpendicular Parallel
	41'-95' Coast Guard vessels	0-45	1000-7500	1.5-15	4-17	0-3	Horizontal	Clear/light Scattered/dark	1-7	Clear Fog Rain	54-100	Perpendicular Parallel

[1] Investigated during Spring 1980 Experiment only.

TABLE 3.26

SWEEP WIDTH ESTIMATES WITH 90-PERCENT CONFIDENCE LIMITS FOR SLAR SEARCHES AT OPTIMUM SEARCH ALTITUDES

(Osmer et al, 1981b)

SLAR Type	Target Type	Sweep Widths			Optimum Search Altitudes (ft)
		Lower 90 Percent Confidence Limit (nm)	Estimate (nm)	Upper 90 Percent Confidence Limit (nm)	
AOSS SLAR	41'-95' Coast Guard Vessels	22.0	23.6	24.9	None determined[1]
	13'-18' Fiberglass Boats without Equipment	6.5	8.0	9.6	2000
	16'-21' Fiberglass or Aluminum Boats with Equipment	8.6	10.4	12.3	2000
	4-6 Man Canopied Life Rafts without Radar Reflectors	5.2	6.3	7.6	2000-3000
	7-Man Non-Canopied Life Raft without Radar Reflector	5.2	6.3	7.6	2000-3000
SLAR/RIP	41'-95' Coast Guard Vessels	38.5	40.8	42.6	None determined[2]
	13'-18' Fiberglass Boats without Equipment	9.7	10.6	11.5	2000-3000
	16'-21' Fiberglass or Aluminum Boats with Equipment	15.7	16.9	18.2	2000-3000
	4-6 Man Canopied Life Rafts without Radar Reflectors	8.1	9.0	10.1	2000-3000
	7-Man Canopied Life Raft without Radar Reflector	10.3	12.0	13.9	2000-3000

[1] Data collected at altitudes from 1000 to 5000 feet.

[2] Data collected at altitudes from 1000 to 7500 feet.

TABLE 3.27

SUMMARY OF SRU RESOURCES
(Osmer et al, 1981b)

SLAR Type	Target Type	Total Search Time (hr)	Detection Opportunities
AOSS	Small boats	15.6	549
	Life rafts	18.3	424
	41'-95' boats	15.6	243
SLAR/RIP	Small boats	26.4	712
	Life rafts	23.0	449
	41'-95' boats	29.6	438

NOTES:
1. Search time is defined as the cumulative number of hours each aircraft spent searching only during the SLAR experiments.
2. Mission times (hours spent equipping for the SLAR experiments, hours spent on-scene, and hours spent transitting to and from the test area except when engaged in other operational missions) are for the AOSS Experiments - Fall 1978, 38.5 hours; Winter 1979, 58.0 hours; Spring 1980, 62.0 hours; and for the SLAR/RIP Experiments -- Fall 1979, 171.7 hours; Spring 1980, 98.0 hours.

Two parameters of interest, SLAR/RIP gain setting and SLAR beam direction relative to wave crest orientation, were controlled systematically for evaluation only during the Spring 1980 Experiment.

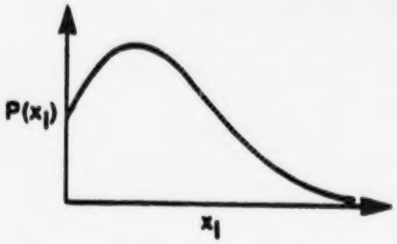


FIGURE 3.31 UNIMODAL CURVE

(Osmer et al, 1981b)

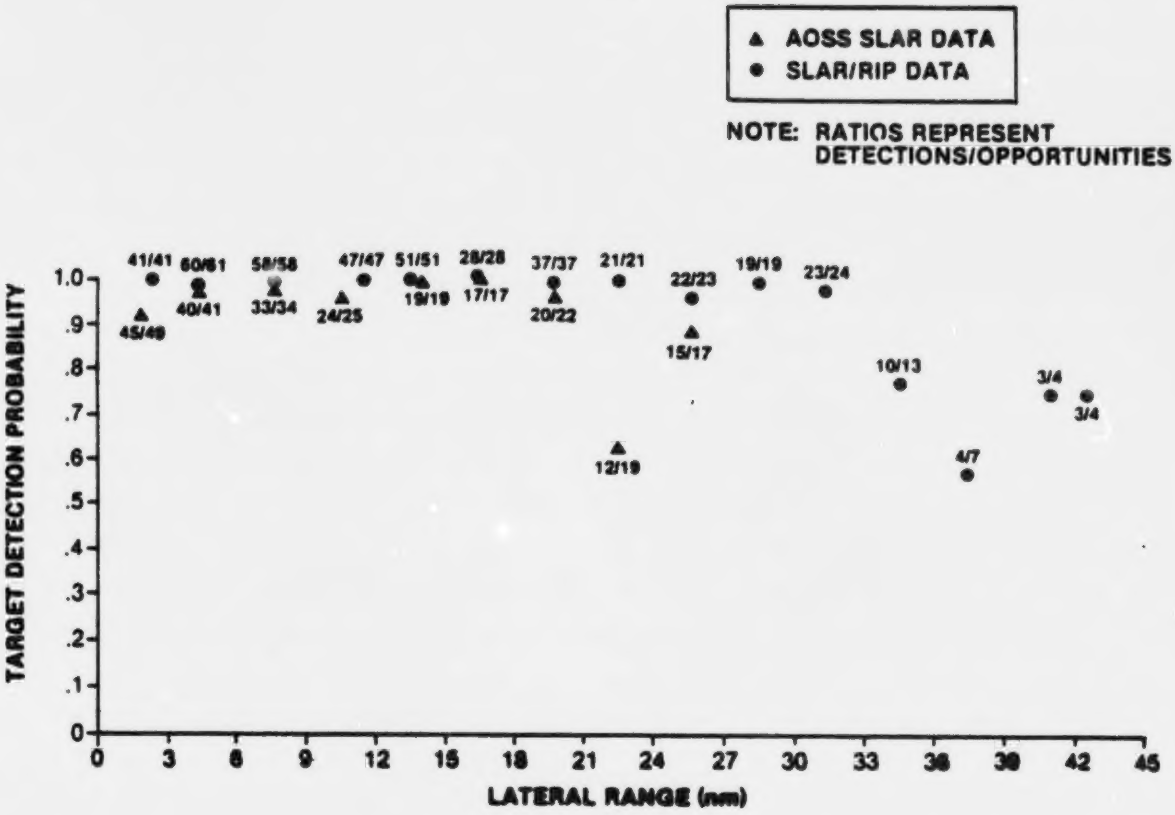


FIGURE 3.32 AOSS AND SLAR/RIP DETECTION OF 41- TO 95-FOOT TARGETS

(Osmer et al, 1981b)

93% detection rate which reduced to 75% beyond a lateral range of 18 nm. For the SLAR/RIP, the detection rate was 97% reducing to 71% beyond a lateral range of 33 nm. For small boats, Table 3.28 shows the influence of parameters on the AOSS system. Figure 3.33 shows the effect of altitude for AOSS. For life rafts using the AOSS system, Table 3.29 shows the influence of parameters and Figure 3.34 the P(x) vs. lateral range data. The influence of parameter data for SLAR/RIP and small boats is given in Table 3.30, and the P(x) vs. lateral range information in Figure 3.35. For one subset of data, the effect of gain change on the SLAR/RIP system was investigated. This information is given in Table 3.31. SLAR/RIP data was also analyzed for life rafts. Table 3.32 shows the influence of parameter data, Figure 3.36 the P(x) vs. lateral range data and Table 3.33 the influence of gain settings. Sweep widths were calculated for both systems for each class of target type. This information is given in Table 3.34. These W are based on LOGODDS regression fits and show that SLAR/RIP is superior to AOSS. The W represent an upper bound for SLAR detection performance.

A special subsection of the analysis by Osmer et al (1981b) was concerned with the influence of ocean wave/SLAR beam orientation on detection performance. Figure 3.37 shows the two orientations tested. Table 3.35 shows the detection probabilities for each class. These data were only tested for swell heights less than 2'. The results were inconclusive.

For large vessels greater than 40' in length, detection in moderate to good weather conditions is almost 100%. Figure 3.38 represents the type of search cover necessary when searching for this target class. When searching for small boats and life rafts, the problem becomes more complex, P(x) is less than unity and varies with lateral range. Figure 3.39 shows the type of search area coverage for the case where S = 24 nm. This type of coverage fails to fill the blind zone. Figure 3.40 shows the P(x) vs. lateral range curve with visual fill in.

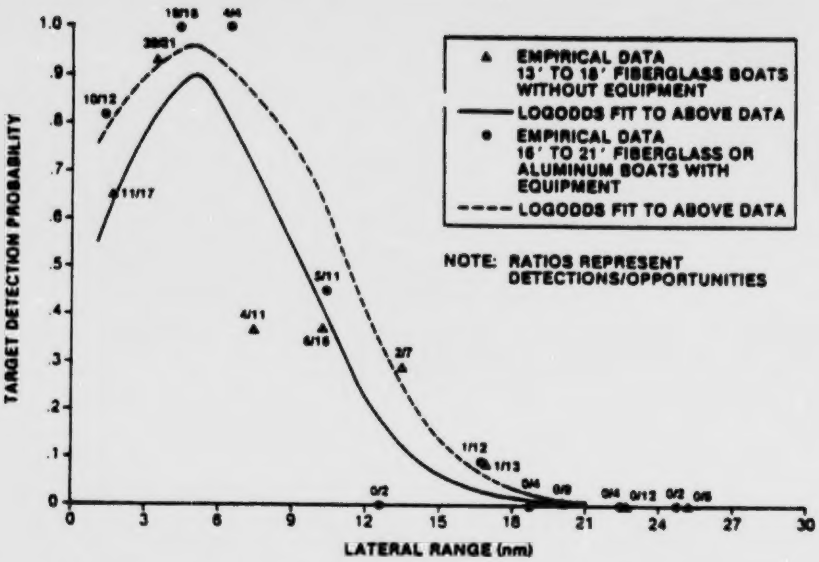
Additional POD data are presented in Osmer et al. (1981a). Figures 3.41 to 3.44 give P(x) vs. lateral range curve data for various tested conditions.

TABLE 3.28

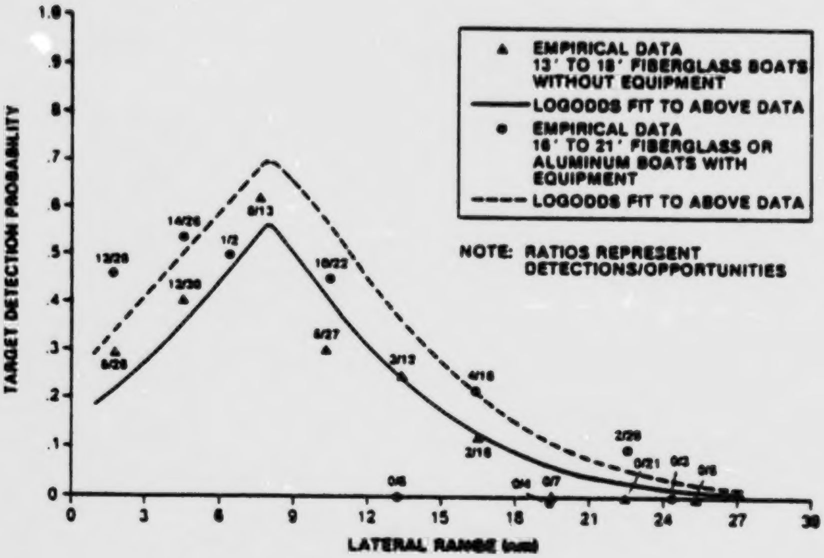
INFLUENCE OF PARAMETERS OF INTEREST ON AOSS SLAR DETECTION OF SMALL BOATS (Lateral Ranges 0 to 18 nm) (Osmer et al, 1981b)

Variable Of Interest	Detections/ Opportu- nities	Target Detection Probability	Mean Values							
			Altitude (ft)	Visibility (nm)	Wind Speed (knots)	Swell Height (ft)	Antenna Polarization (% vertical/ % horizontal)	Image Background (% scattered/ dark)	Precipitation (% of data where present)	Relative Humidity (%)
Target Type										
[3] 13'-18' Fiberglass Boats without Equipment	101/284	.36	2681	11.1	8.0	1.5	52/48	32	2	72
[3] 16'-21' Fiberglass or Aluminum Boats with Equipment	79/159	.50	3208	11.4	8.6	1.1	60/40	28	3	72
Altitude (ft)										
[2] 1000-1300	16/73	.22	1049	10.4	9.1	2.7	40/60	66	0	67
[3] 2000	82/144	.57	2000	12.5	7.6	1.1	60/40	37	2	72
[3] 3000-3300	49/126	.39	3012	10.6	8.7	1.0	40/60	23	6	75
[2] [3] 4500-5500	33/100	.33	5000	10.6	7.9	1.1	70/30	6	0	71
Visibility (nm)										
1-1.5	28/74	.38	3548	1.5	4.2	0.9	58/42	0	14	88
8-18	152/369	.41	2662	13.1	9.1	1.4	54/46	37	0	68
Wind Speed (knots)										
3-10	152/359	.42	2861	11.1	7.0	1.0	50/50	26	3	71
11-17	28/84	.33	2607	11.7	13.7	2.7	60/40	50	0	64
Swell Height (ft)										
0.5-1.0	136/329	.41	3020	11.0	7.1	0.9	54/46	22	3	75
2-4	44/114	.39	2198	11.7	11.6	2.7	55/45	57	0	63
Antenna Polarization										
Horizontal	87/203	.43	2657	11.1	7.9	1.4	0/100	16	2	72
Vertical	93/240	.39	2937	11.2	8.5	1.3	100/0	0	3	74
Image Background										
Clear/Light	122/307	.40	3169	10.8	7.6	1.1	44/56	0	3	70
Scattered/Dark	58/136	.43	1995	12.1	9.8	1.8	23/77	100	0	73
Precipitation										
[1] None	173/433	.40	2811	11.4	8.3	1.3	54/46	31	0	71
[1] Present	7/10	.70	2700	1.4	4.2	1.0	60/40	0	100	100
Relative Humidity (%)										
55-75	107/265	.40	2578	12.5	9.3	1.6	50/50	42	0	63
76-100	73/178	.41	3152	9.2	6.7	1.0	60/40	13	6	84

[1] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .10 alpha level.
[2] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .05 alpha level.
[3] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .01 alpha level.



A. 2000-Foot Search Altitude



B. 3000- To 5500-Foot Search Altitude

FIGURE 3.33 AOSS SLAR DETECTION OF SMALL BOATS

(Osmer et al, 1981b)

TABLE 3.29

INFLUENCE OF PARAMETERS OF INTEREST ON AOSS SLAR DETECTION OF LIFE RAFTS
(Lateral Ranges 0 to 18 nm)
(Osmer et al, 1981b)

Variable of Interest	Detections/ Opportunities	Target Detection Probability	Mean Values							
			Altitude (ft)	Visibility (nm)	Wind Speed (knots)	Swell Height (ft)	Antenna Polarization (% vertical/ % horizontal)	Image Background (% scattered/ dark)	Precipitation (% of data where present)	Relative Humidity (%)
Target Type										
[3] 4-6 Man Canopied Rafts without Radar Reflectors	75/251	.30	3134	10.6	9.2	1.2	50/50	28	5	82
[3] 7-Man Non-Canopied Rafts without Radar Reflectors	15/88	.17	2782	6.6	13.6	1.8	60/40	50	16	80
Altitude (ft)										
500-1000	1/18	.06	583	10.1	28.3	3.0	33/67	1	0	80
[3] 2000	42/99	.42	2000	11.7	7.6	1.0	60/40	37	0	84
2500[4]	4/39	.10	2500[4]	5.4	20.3	2.7	40/60	85	54	82
[3] 3000	36/93	.39	3000	9.4	8.5	1.0	40/60	18	8	78
[3] 4000-5500	7/90	.08	4960	9.0	7.6	1.1	71/29	6	0	81
Visibility (nm)										
[2] 0-6	22/116	.19	3404	2.1	8.5	1.3	59/41	20	23	86
[2] 10-15	68/223	.30	2854	13.4	11.3	1.4	53/47	41	0	72
Wind Speed (knots)										
3-12	79/277	.29	3166	9.6	7.3	1.0	60/40	24	0	81
17-30	11/62	.18	2492	9.2	23.8	2.7	50/50	77	23	78
Swell Height (ft)										
[2] 0.5-1.0	71/236	.30	3216	9.8	7.0	0.9	55/45	18	4	78
[2] 1.5-3.0	19/103	.18	2645	9.0	18.0	2.4	56/44	71	17	75
Antenna Polarization										
Horizontal	43/152	.28	2819	9.5	10.7	1.4	0/100	24	6	88
Vertical	47/187	.25	3224	9.5	10.0	1.3	100/0	42	4	81
Image Background										
Clear/Light	57/224	.25	3412	9.1	7.7	1.0	49/51	0	7	84
Scattered/Dark	33/115	.29	2323	10.5	15.5	1.9	32/68	100	10	79
Precipitation										
[2] None	88/312	.28	3090	10.3	9.7	1.3	60/40	33	0	83
[2] Present	2/27	.07	2593	1.0	18.3	2.1	50/50	44	100	92
Relative Humidity (%)										
59-70	37/119	.31	3210	13.2	10.1	1.3	50/50	42	0	84
77-100	53/220	.24	2956	7.5	10.4	1.4	58/42	30	12	63

[1] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .10 alpha level.
[2] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .05 alpha level.
[3] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .01 alpha level.
[4] 2500-foot altitude characterized by very poor environmental conditions (wind speed/swell/precipitation).

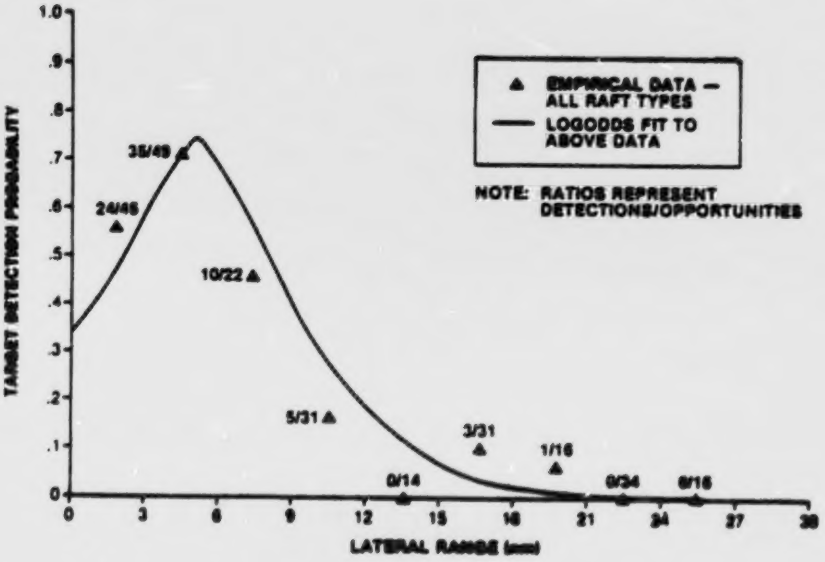


FIGURE 3.34 AOSS SLAR DETECTION OF LIFE RAFTS
(2000- and 3000-foot search altitudes)
(Osmer et al, 1981b)

TABLE 3.30

INFLUENCE OF PARAMETERS OF INTEREST ON SLAR/RIP DETECTION OF SMALL BOATS

(Lateral Ranges 0 to 24 nm)

(Osmer et al, 1981b)

Variable of Interest	Detections/ Opportunities	Target Detection Probability	Mean Values							
			Altitude (ft)	Visibility (nm)	Wind Speed (knots)	Swell Height (ft)	Antenna Polarization (% vertical/ % horizontal)	Image Background (% scattered/ dark)	Precipitation (% of data where present)	Relative Humidity (%)
Target Type										
[3] 13'-18' Fiberglass Boats without Equipment	173/383	.45	3381	10.1	9.9	1.5	0/100	54	7	78
16'-21' Fiberglass or Aluminum Boats with Equipment	158/229	.69	3332	11.5	10.8	1.1	0/100	58	0	74
Altitude (ft)										
[1] 2000	114/202	.56	2000	10.2	9.6	1.4	0/100	51	3	80
3000	118/198	.60	3000	11.2	11.1	1.4	0/100	65	5	81
5000	99/212	.47	5000	10.5	10.1	1.3	0/100	51	6	83
Visibility (nm)										
[2] 1.5-7	69/152	.45	3474	5.5	9.2	2.2	0/100	32	19	83
8-15	262/460	.57	3326	12.3	10.6	1.1	0/100	63	0	75
Wind Speed (knots)										
4-10	202/360	.56	3514	10.7	7.8	1.3	0/100	60	2	82
11-17	129/252	.51	3147	10.5	13.7	1.4	0/100	50	9	80
Swell Height (ft)										
0-1	229/424	.54	3455	11.3	10.1	0.9	0/100	58	2	77
2-3	102/188	.54	3154	9.1	10.6	2.5	0/100	51	12	77
Antenna Polarization										
Horizontal Only	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Image Background										
[3] Clear/Light	111/272	.41	3404	8.8	10.3	1.5	0/100	0	5	83
Scattered/Dark	220/340	.65	3329	12.0	10.2	1.3	0/100	100	5	81
Precipitation										
[3] None	325/583	.56	3354	11.0	10.0	1.3	0/100	56	0	65
Present	6/29	.21	3655	3.8	14.6	2.1	0/100	55	100	98
Relative Humidity (%)										
[3] 59-70	138/227	.61	3370	11.6	9.4	1.1	0/100	61	0	65
77-100	193/385	.50	3558	10.1	10.7	1.5	0/100	52	8	84

[1] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .10 alpha level.
[2] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .05 alpha level.
[3] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .01 alpha level.

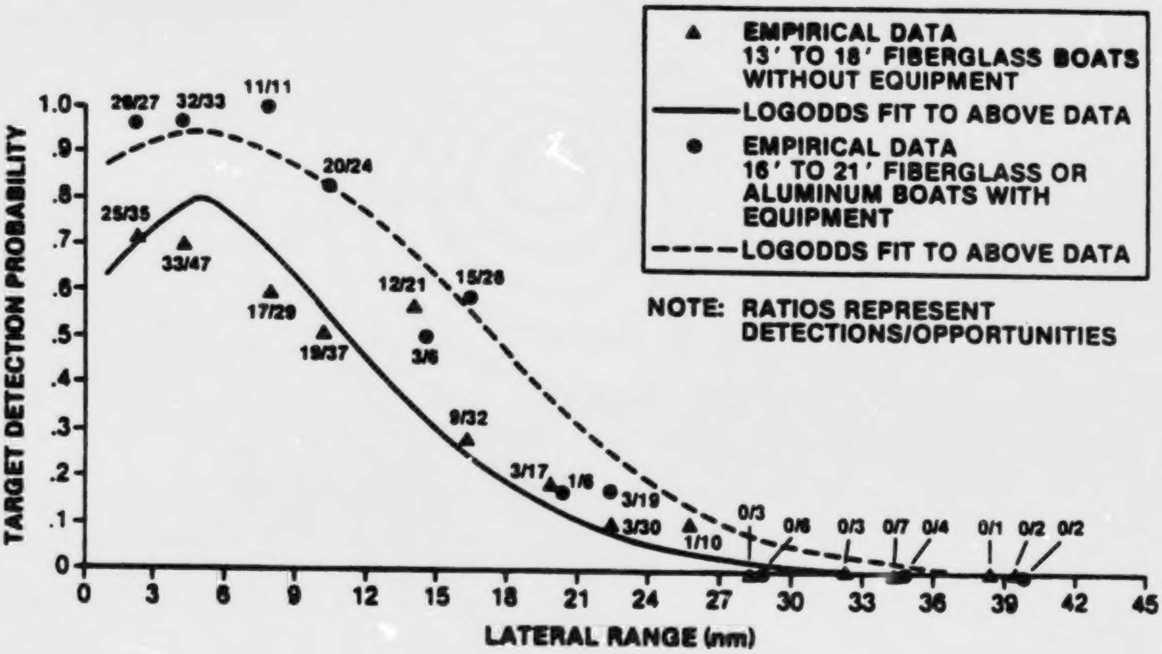


FIGURE 3.35 SLAR/RIP DETECTION OF SMALL BOATS
(2000- to 3000-foot search altitudes)
(Osmer et al, 1981b)

TABLE 3.31

INFLUENCE OF GAIN SETTING ON SLAR/RIP DETECTION OF SMALL BOATS DURING THE SPRING 1980 EXPERIMENT

(Lateral Ranges 0 to 24 nm)

(Osmer et al, 1981b)

Gain Setting	Altitude (ft)	
	2000/3000	5000
	Detections/Opportunities (Probability)	Detections/Opportunities (Probability)
2	74/132 (.56) [1]	17/46 (.37) [2]
3	129/177 (.73) [1]	37/81 (.46) [2]
4	Not tested	29/44 (.66) [2]

[1] Chi-square test indicates the difference between detection/opportunity ratios is significant at the .01 alpha level.

[2] Chi-square test indicates the difference between detection/opportunity ratios is significant at the .05 alpha level.

TABLE 3.32

INFLUENCE OF PARAMETERS OF INTEREST ON SLAR/RIP DETECTION OF LIFE RAFTS

(Lateral Ranges 0 to 18 nm)

(Osmer et al, 1981b)

Variable of Interest	Detections/ Opportunities	Target Detection Probability	Mean Values							
			Altitude (ft)	Visibility (nm)	Wind Speed (knots)	Swell Height (ft)	Antenna Polarization (% vertical/ % horizontal)	Image Background (% scattered/ dark)	Precipitation (% of data where present)	Relative Humidity (%)
Target Type										
4-6 Man Canopied Rafts with Radar Reflectors	10/16	.62	3531	11.1	4.9	0.1	0/100	19	0	91
[1] 4-6 Man Canopied Rafts without Radar Reflectors	119/246	.48	3390	11.6	10.6	1.1	0/100	67	0	81
7-Man Non-Canopied Rafts without Radar Reflectors	31/48	.65	3250	12.6	6.9	0.5	0/100	50	0	82
Altitude (ft)										
1000	0/4	.00	1000	13.0	14.0	2.0	0/100	50	0	82
[3] 2000	52/92	.56	2000	10.2	9.4	1.1	0/100	54	0	74
3000	67/111	.60	3000	12.2	10.4	0.9	0/100	59	0	82
5000	41/98	.42	5000	12.4	9.7	0.9	0/100	71	0	84
7500	0/5	.00	7500	15.0	7.0	1.0	0/100	60	0	81
Visibility (nm)										
[2] 1.5-7.0	22/30	.73	2900	4.8	9.0	1.1	0/100	27	0	75
8.0-15.0	138/280	.49	3434	12.5	9.8	1.0	0/100	65	0	76
Wind Speed (knots)										
[3] 4-10	114/192	.59	3628	12.6	7.4	0.7	0/100	66	0	79
11-17	46/118	.39	2983	11.4	13.6	1.4	0/100	55	0	82
Swell Height (ft)										
0-1	139/263	.53	3527	11.6	9.1	0.8	0/100	61	0	77
2-3	21/47	.45	2547	12.3	13.5	2.3	0/100	64	0	69
Antenna Polarization										
Horizontal Only	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Image Background										
Clear/Light	62/119	.52	3193	9.9	9.6	0.9	0/100	0	0	83
Scattered/Dark	98/191	.51	3516	12.9	9.9	1.1	0/100	100	0	74
Precipitation										
None	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Relative Humidity (%)										
54-70	65/113	.58	3336	11.8	9.7	1.0	0/100	71	0	64
77-94	95/197	.48	3408	11.7	9.8	1.8	0/100	56	0	83

[1] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .10 alpha level.
[2] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .05 alpha level.
[3] Chi-Square Test indicates the difference between detection/opportunity ratios is significant at the .01 alpha level.

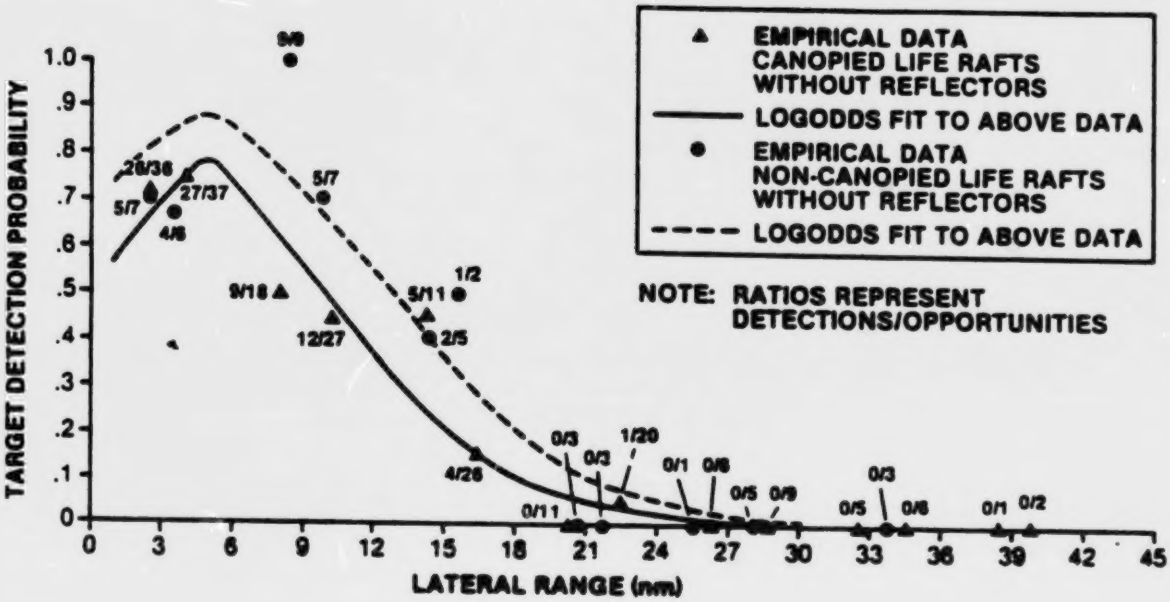


FIGURE 3.36 SLAR/RIP DETECTION OF LIFE RAFTS
(2000- to 3000-foot search altitudes)

(Osmer et al, 1981b)

TABLE 3.33

INFLUENCE OF GAIN SETTING ON SLAR/RIP DETECTION OF LIFE RAFTS DURING THE SPRING 1980 EXPERIMENT

(Lateral Ranges 0 to 18 nm)

(Osmer et al, 1981b)

Gain Setting	Altitude (ft)			
	2000/3000		5000	
	Detections/Opportunities (Probability)		Detections/Opportunities (Probability)	
2	32/67 (.48)	[1]	4/23 (.17)	
3	55/81 (.68)		19/43 (.44)	[1]
4			15/26 (.58)	

[1] Chi-square test indicates the difference between detection/opportunity ratios is significant at the .05 alpha level.

TABLE 3.34

SWEEP WIDTH ESTIMATES WITH 90-PERCENT CONFIDENCE LIMITS FOR SLAR SEARCHES AT OPTIMUM SEARCH ALTITUDES

(Osmer et al, 1981b)

SLAR Type	Target Type	Sweep Widths			Optimum Search Altitudes (ft)
		Lower 90-Percent Confidence Limit (nm)	Estimate (nm)	Upper 90-Percent Confidence Limit (nm)	
AOSS SLAR	41'-95' Coast Guard Vessels	22.0	23.6	24.9	None determined[1]
	13'-18' Fiberglass Boats without Equipment	6.5	8.0	9.6	2000
	16'-21' Fiberglass or Aluminum Boats with Equipment	8.6	10.4	12.3	2000
	4-6 Man Canopied Life Rafts without Radar Reflectors	5.2	6.3	7.6	2000-3000
	7-Man Non-Canopied Life Rafts without Radar Reflector	5.2	6.3	7.6	2000-3000
SLAR/RIP	41'-95' Coast Guard Vessels	38.5	40.8	42.6	None determined[2]
	13'-18' Fiberglass Boats without Equipment	9.7	10.6	11.5	2000-3000
	16'-21' Fiberglass or Aluminum Boats with Equipment	15.7	16.9	18.2	2000-3000
	4-6 Man Canopied Life Rafts without Radar Reflectors[3]	8.1	9.0	10.1	2000-3000
	7-Man Non-Canopied Life Rafts without Radar Reflector	10.3	12.0	13.9	2000-3000

[1] Data collected at altitudes from 1000 to 5000 feet.

[2] Data collected at altitudes from 1000 to 7500 feet.

[3] Data collected under higher wind conditions than for non-canopied life rafts; see Table 3-5.

TABLE 3.35

INFLUENCE OF OCEAN WAVE/SLAR BEAM ORIENTATION ON DETECTION PERFORMANCE

(Spring 1980 data only)

(Osmer et al, 1981b)

Sensor/Target Type	Wave/Beam Orientation	
	Perpendicular	Parallel
	Detections/Opportunities (Probability)	Detections/Opportunities (Probability)
SLAR/RIP Small Boats[1]	141/233 (.61)	145/247 (.59)
SLAR/RIP Life Rafts[2,3]	65/109 (.60)	60/131 (.46)
AOSS SLAR Small Boats[2]	73/179 (.41)	78/171 (.46)
AOSS SLAR Life Rafts[2,4]	36/138 (.26)[4]	47/127 (.37)

[1] Lateral ranges, 0 to 24 nm only.

[2] Lateral ranges, 0 to 18 nm only.

[3] Chi-square test indicates the difference between detection/opportunity ratios is significant at the .05 alpha level.

[4] Chi-square test indicates the difference between detection/opportunity ratios is significant at the .10 alpha level.

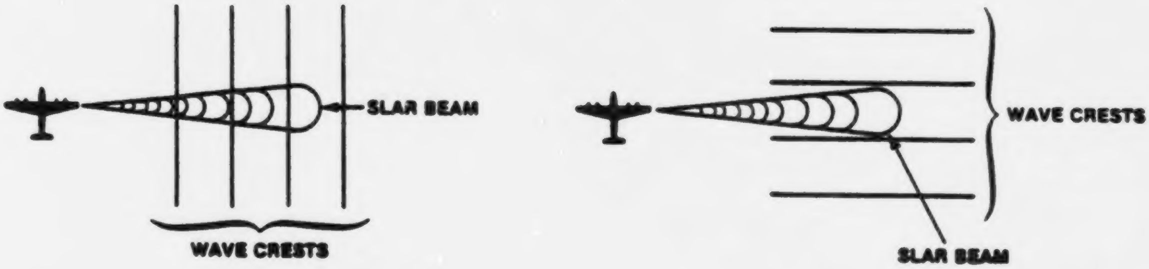

SLAR BEAM
WAVE CRESTS
WAVE CRESTS
SLAR BEAM

FIGURE 3.37 PERPENDICULAR ORIENTATION, AND PARALLEL ORIENTATION
(Osmer et al, 1981b)

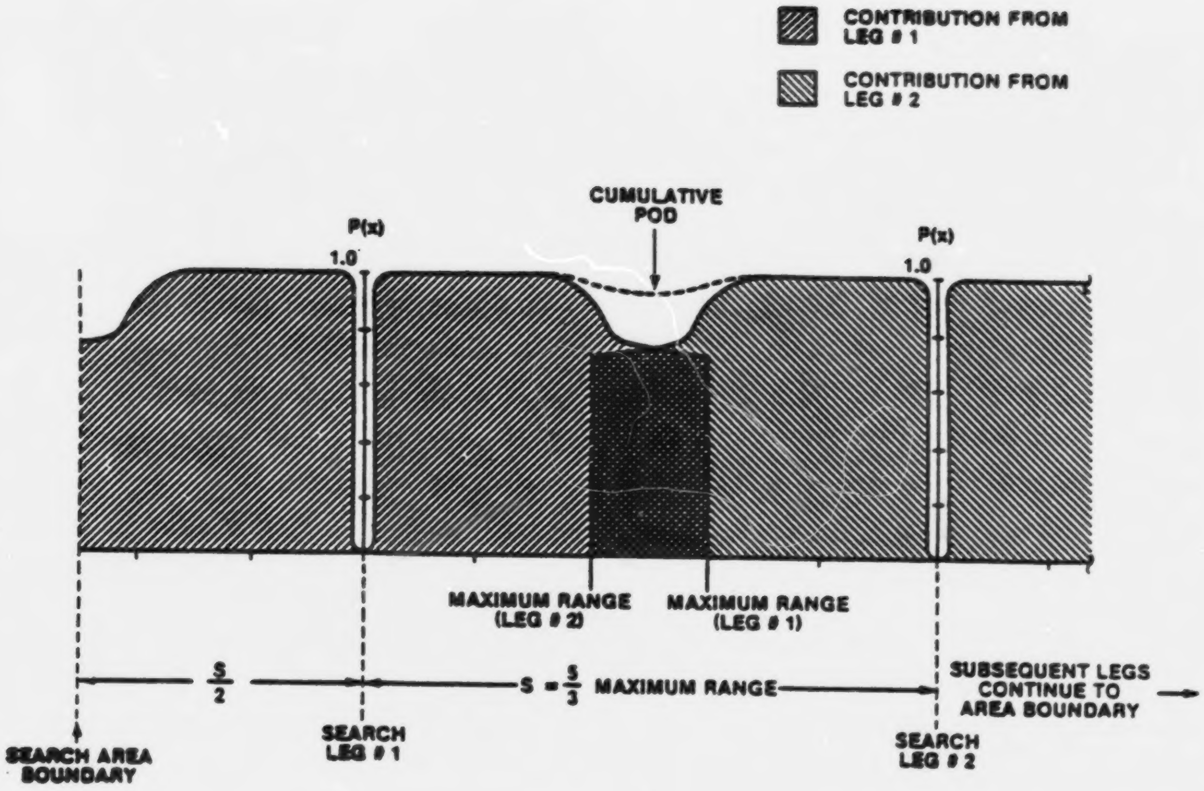

CONTRIBUTION FROM LEG # 1
CONTRIBUTION FROM LEG # 2
CUMULATIVE POD
P(x)
1.0
P(x)
1.0
MAXIMUM RANGE (LEG # 2)
MAXIMUM RANGE (LEG # 1)
S/2
S = 5/3 MAXIMUM RANGE
SUBSEQUENT LEGS CONTINUE TO AREA BOUNDARY
SEARCH AREA BOUNDARY
SEARCH LEG # 1
SEARCH LEG # 2

FIGURE 3.38 EXAMPLE OF SEARCH AREA COVERAGE: SLAR SEARCHING FOR 41- TO 95-FOOT METAL-HULLED BOATS

(Osmer et al, 1981b)

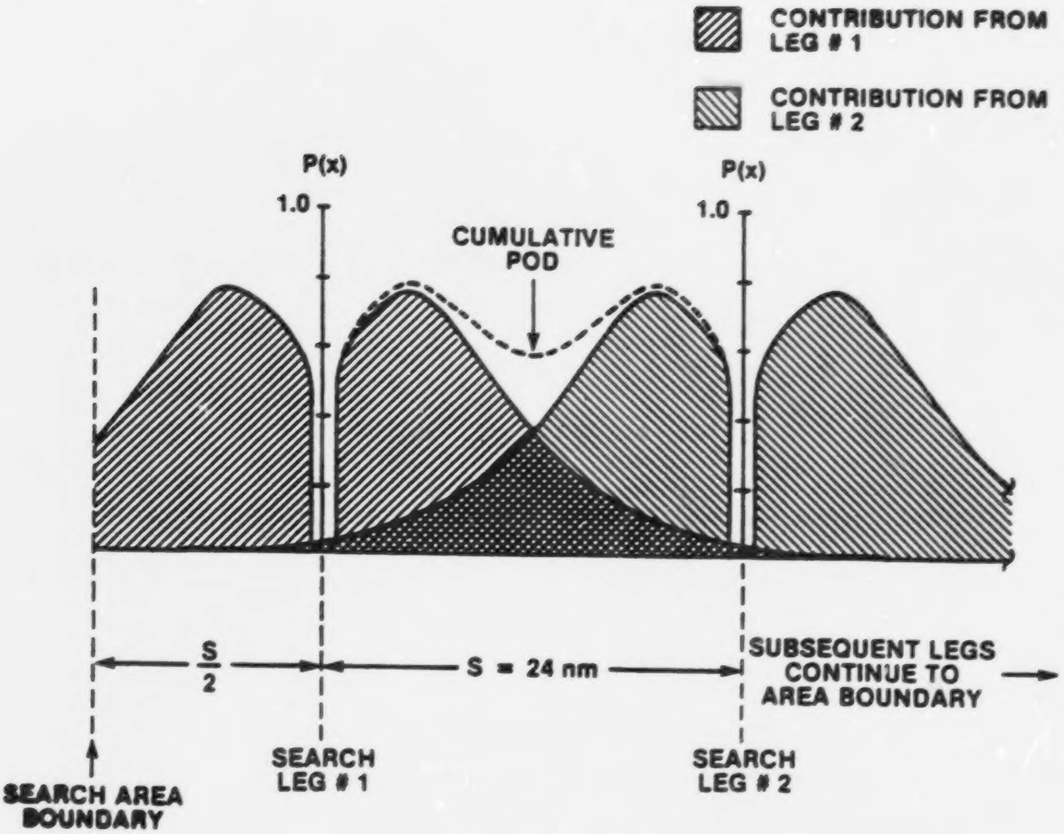

CONTRIBUTION FROM LEG # 1
CONTRIBUTION FROM LEG # 2
P(x)
1.0
P(x)
1.0
CUMULATIVE POD
S/2
S = 24 nm
SUBSEQUENT LEGS CONTINUE TO AREA BOUNDARY
SEARCH AREA BOUNDARY
SEARCH LEG # 1
SEARCH LEG # 2

FIGURE 3.39 EXAMPLE OF SEARCH AREA COVERAGE:
SLAR/RIP SEARCHING FOR CANOPIED LIFE RAFTS
(2000- to 3000-foot search altitudes)

(Osmer et al, 1981b)

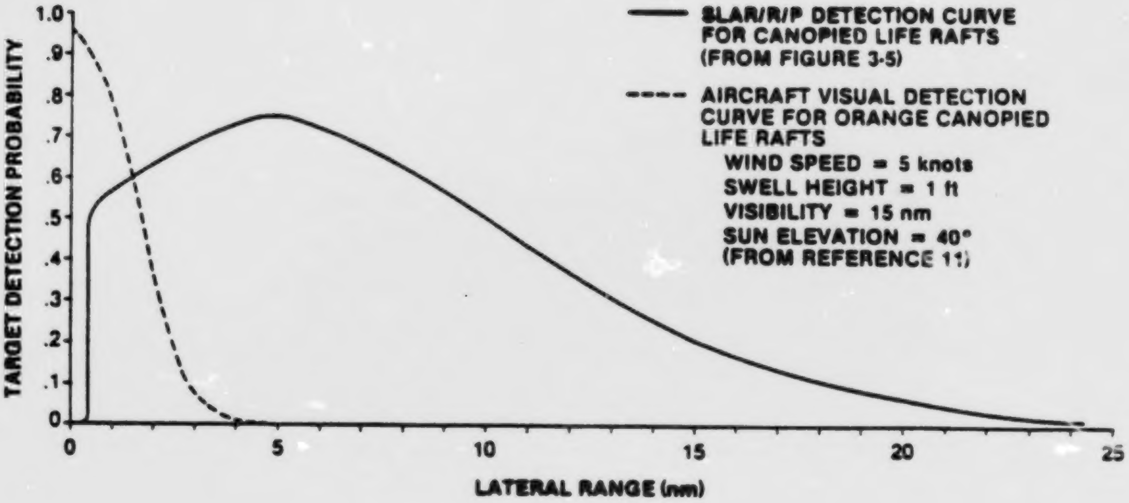


FIGURE 3.40 EXAMPLE OF COMBINED SLAR/RIP
AND VISUAL LATERAL RANGE CURVES
(canopied life raft target, good conditions)

(Osmer et al, 1981b)

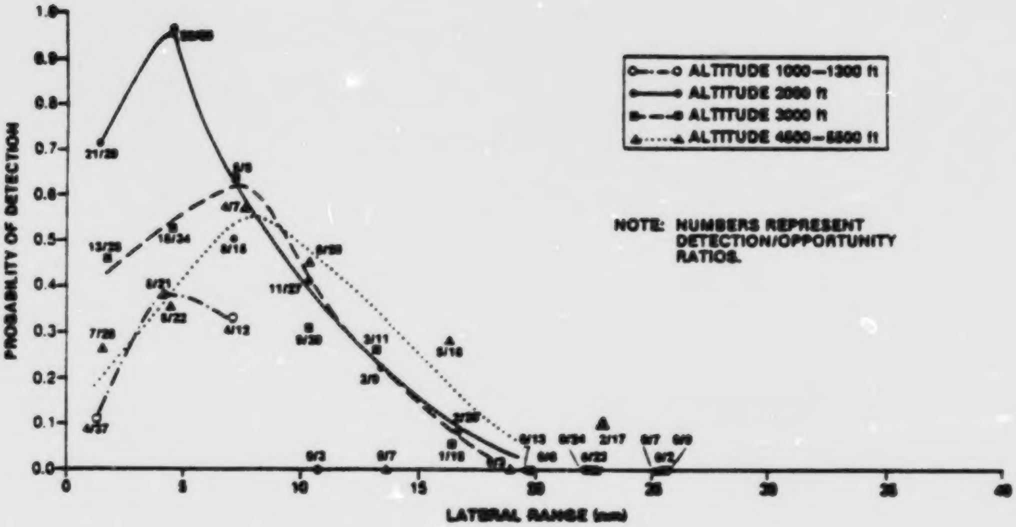


FIGURE 3.41 ALTITUDE EFFECTS ON AOSS SLAR DETECTION OF SMALL BOATS (Osmer et al, 1981a)

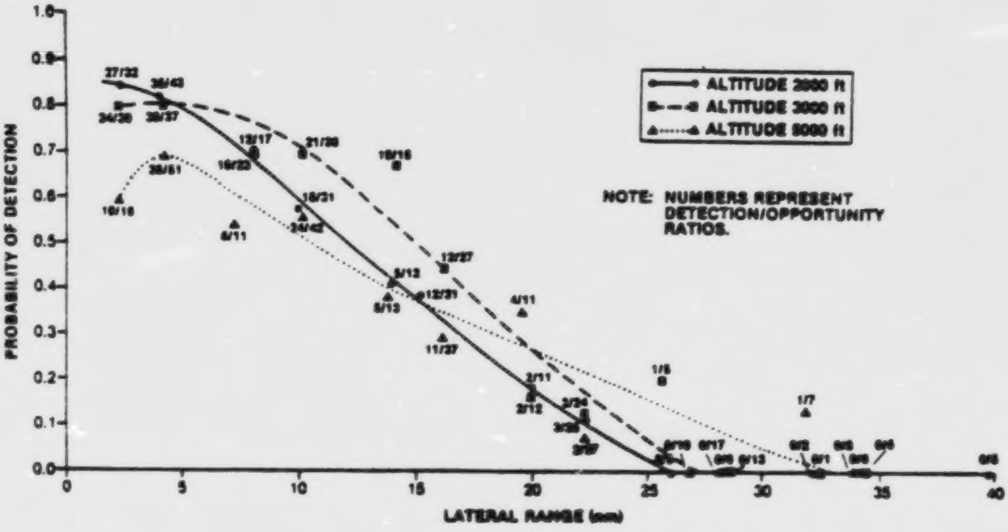
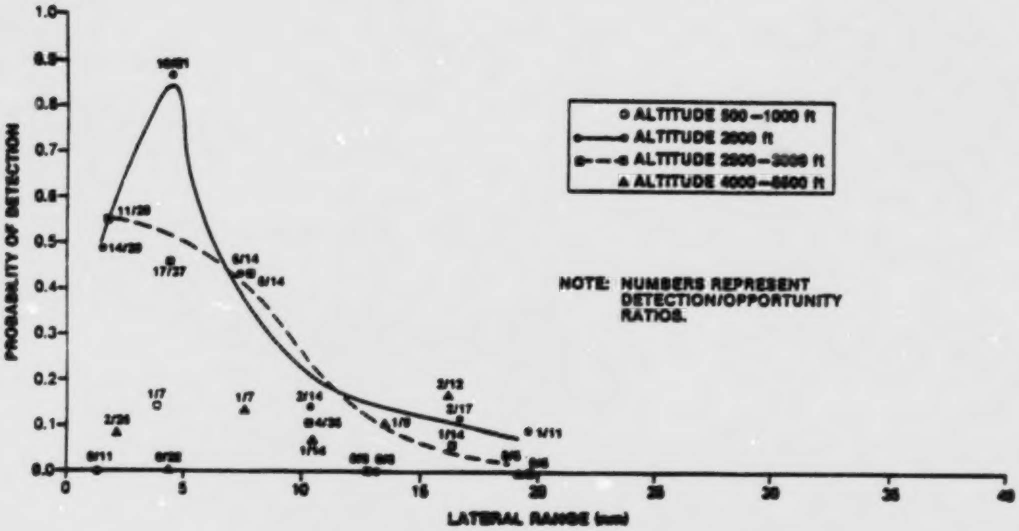
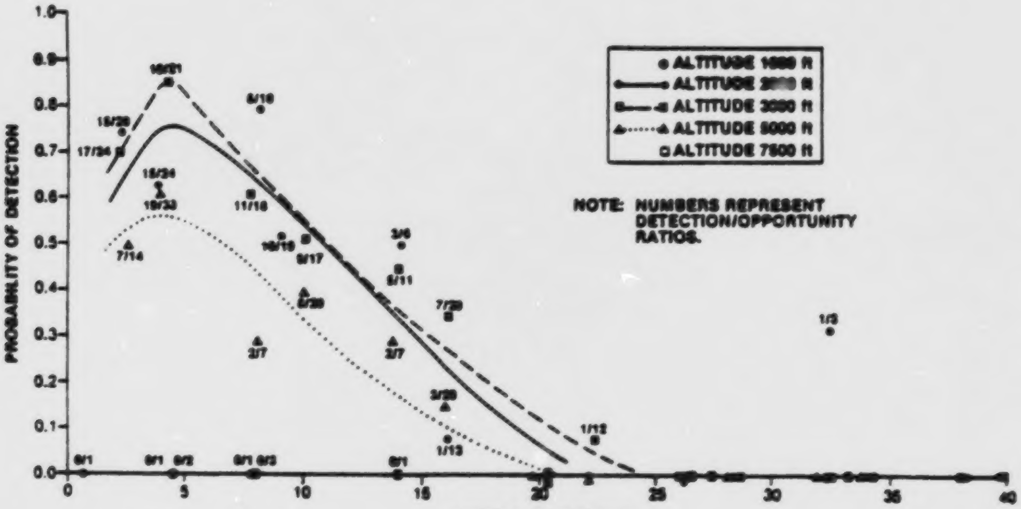


FIGURE 3.42 ALTITUDE EFFECTS ON SLAR/RIP DETECTION OF SMALL BOATS (Osmer et al, 1981a)



NOTE: NUMBERS REPRESENT DETECTION/OPPORTUNITY RATIOS.

FIGURE 3.43 ALTITUDE EFFECTS ON AOSS SLAR DETECTION OF LIFE RAFTS (Osmer et al, 1981a)



NOTE: NUMBERS REPRESENT DETECTION/OPPORTUNITY RATIOS.

FIGURE 3.44 ALTITUDE EFFECTS ON SLAR/RIP DETECTION OF LIFE RAFTS (Osmer et al, 1981a)

3.2.2 Forward Looking Airborne Radars (FLAR)

3.2.2.1 Literature Review

The U.S.C.G. carried out an experiment to compare visual and forward looking airborne radar (FLAR) detection performance. FLAR searches were conducted for small boats with and without radar reflectors, and orange canopied life rafts (4- to 6-man). The surveillance was carried out using a fixed-wing aircraft (Ketchen et al., 1983). It was found that increasing search altitude, increasing significant wave height and absence of radar reflectors all significantly degraded FLAR detection performance. It was also found that relative ocean wave direction and relative wind direction do not exert a clear influence on FLAR detection performance. It was recommended that FLAR searches for small boats and life rafts be conducted at altitudes of 500' or less and that the five nautical mile range scale be used for small target searches.

Additional FLAR studies are reported in Ketchen et al (1984). This study evaluated the detection performance of several FLARs. Only one of the FLARs tested was able to detect 1 m^2 targets in sea states greater than 2, and it was also the only system capable of initial target detection of 100 m^2 targets at ranges of 74 to 80 nm. This study was basically a sensor evaluation study for U.S.C.G. requirements but the limited probability data is suitable for evaluation.

3.2.2.2 Sensor Description

The best method to describe a FLAR is to call it a marine ship type radar with better resolution, improved detection sensitivity and flexible system controls. They are often dual-mode, search/weather radar systems. They have, among their special features, sea clutter envelope processing, antenna tilt, frequency agility, long or short pulse mode, heading stabilization and range capability beyond 150 nm. Usually, different display modes can be put on the monitor. Although this is only a very general description, it suffices for the technical description of sensor requirements for this report.

3.2.2.3 Probability of Detection

In Ketchen et al (1983) one measure of search performance was used to evaluate the FLAR data. Detection performance was evaluated by calculating cumulative detection probability as a function of range to the target for various parameter combinations and sweep widths.

Cumulative detection probability (CDP) as a function of range is a useful measure of sensor detection performance. It provides a better picture of how target detection probability increases as sensor-to-target range closes than detection range statistics alone. CDP is the probability that a target will have been detected by the time it closes to a given range. It is a monotonically increasing function of closing range. Figure 3.45 shows the CDP vs. range function for a typical radar. Where the slope is steepest, most detections occur. Where the curve is horizontal, detection of additional targets ceases. CDP curves should not be confused with lateral range curves, CDP curves cannot be used to compute W.

The data set for FLAR detection was not very large, but preliminary probability data were derived by Ketchen et al. (1983). The influence of search altitude on FLAR detection performance is given in Table 3.36. These data are sorted by significant wave height and altitude. Table 3.37 shows the effects of significant wave height and target type. Table 3.38 summarizes the effects of wave direction for the rough sea data. Table 3.39 shows the data sorted according to relative wind direciton. Figures 3.46 and 3.47 give a comparison of CDP vs. range for canopied life rafts with and without radar reflectors, respectively. A comparison is given between Figure 3.48 and 3.49 for life rafts and boats with radar reflectors.

Ketchen et al. (1984) provides further CDP data. Table 3.40 gives raw detection data for the four FLARs tested and Table 3.41 shows the comparisons between the various systems for two different sea states. The authors present four sets of CDP vs. range curves for their field data. Figure 3.50 gives CDP curves for targets with radar reflectors and sea state 1 and Figure 3.51 gives comparable sea state data for similar targets without radar reflectors. Figures 3.52 and 3.53 give the same data for sea state 2. The authors estimated FLAR sweep widths for 1 m^2 targets in sea states 1, 3 and 5 (Figure 3.54). FLAR systems detect targets but provide very little information

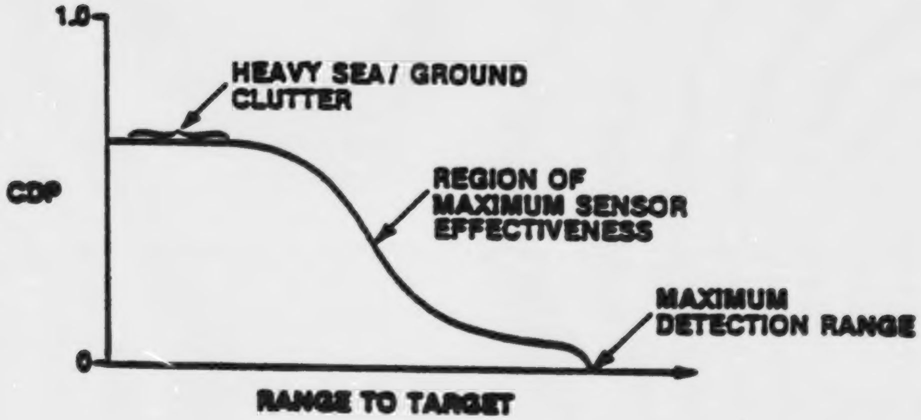


FIGURE 3.45 TYPICAL CDP-VERSUS-RANGE CURVE FOR RADAR
(Ketchen et al, 1983)

TABLE 3.36

EFFECTS OF SEARCH ALTITUDE ON FLAR DETECTION PERFORMANCE

(Ketchen et al, 1983)

SIGNIFICANT WAVE HEIGHT (ft)	SEARCH ALTITUDE (ft)	NUMBER OF DETECTION OPPORTUNITIES	NUMBER OF DETECTIONS	PERCENT DETECTED	MEAN DETECTION RANGE (nm)
1.5	300	7	1	14	2.0
	500	19	9	47	1.7
	1000	0	-	-	-
3.5 to 4.5	300	26	4	15	2.4
	500	29	3	10	2.7
	1000	8	0	0	-

TABLE 3.37

EFFECTS OF SIGNIFICANT WAVE HEIGHT AND TARGET TYPE ON FLAR DETECTION PERFORMANCE

(Ketchen et al, 1983)

SIGNIFICANT WAVE HEIGHT (ft)	TARGET TYPE	NUMBER OF DETECTION OPPORTUNITIES	NUMBER OF DETECTIONS	PERCENT DETECTED	MEAN DETECTION RANGE (nm)
1.5	16-foot fiberglass boat without engine or radar reflector	0	-	-	-
	16-foot fiberglass boat with radar reflector	12	6	50	1.8
	4- to 6-man canopied life raft	14	4	29	1.7
3.5 to 4.5	16-foot fiberglass boat without engine or radar reflector	22	2	9	2.5
	16-foot fiberglass boat with radar reflector	2	1	50	2.2
	4- to 6-man canopied life raft	31	4	13	2.6

TABLE 3.38

EFFECTS OF RELATIVE WAVE DIRECTION ON FLAR DETECTION PERFORMANCE

(3.5- to 4.5-foot seas; 6- to 19-knot winds)

(Ketchen et al, 1983)

RELATIVE WAVE DIRECTION	NUMBER OF DETECTION OPPORTUNITIES	NUMBER OF DETECTIONS	PERCENT DETECTED	MEAN DETECTION RANGE (nm)
Aircraft heading opposite ocean wave direction	11	2	18	2.4
Aircraft heading aligned with ocean wave direction	13	0	0	-
Aircraft heading parallel to wave crests and troughs	31	5	16	2.6

TABLE 3.39

EFFECTS OF RELATIVE WIND DIRECTON ON
FLAR DETECTION PERFORMANCE
(1.5- to 4.5-foot seas; 6- to 19-knot winds)
(Ketchen et al, 1983)

RELATIVE WIND DIRECTION	NUMBER OF DETECTION OPPORTUNITIES	NUMBER OF DETECTIONS	PERCENT DETECTED	MEAN DETECTION RANGE (nm)
Upwind	22	4	17	2.7
Downwind	23	6	26	1.7
Crosswind	36	7	19	2.0

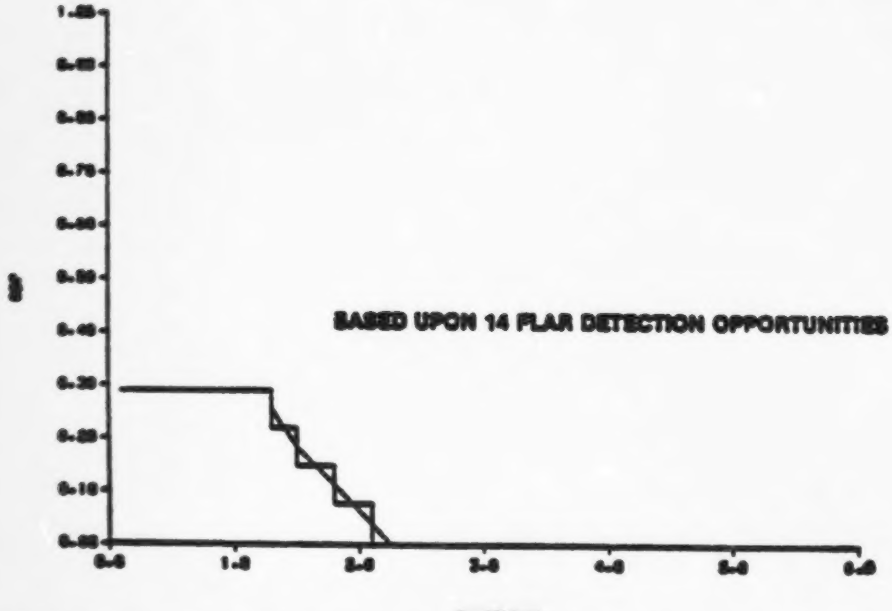


FIGURE 3.46 CDP VERSUS RANGE FOR AN/APS-127 SEARCHING FOR CANOPIED LIFE RAFTS WITHOUT RADAR RELECTORS (1.5-foot seas) (Ketchen et al, 1983)

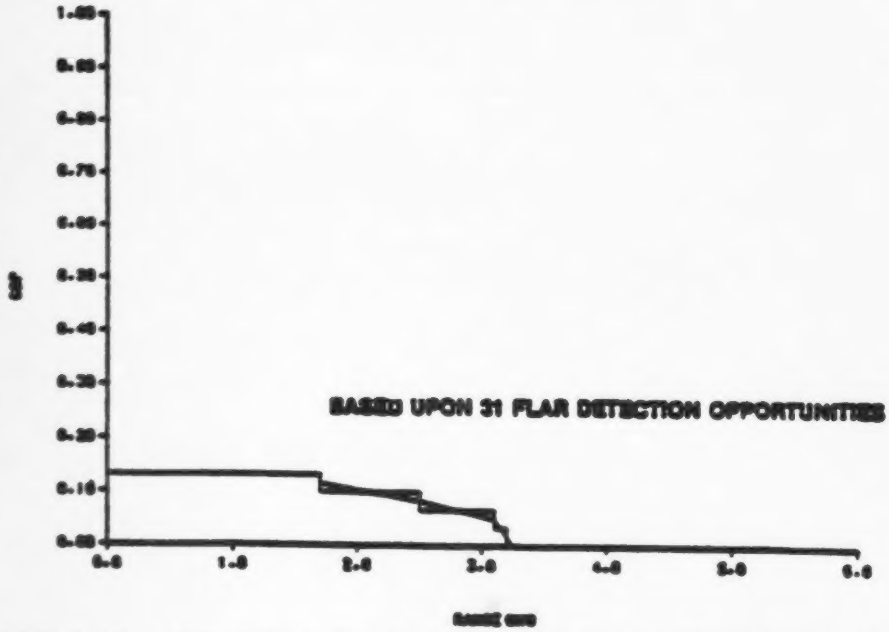


FIGURE 3.47 CDP VERSUS RANGE FOR AN/APS-127 SEARCHING FOR CANOPIED LIFE RAFTS WITHOUT RADAR REFLECTORS (3.5- to 4.5-foot seas) (Ketchen et al, 1983)

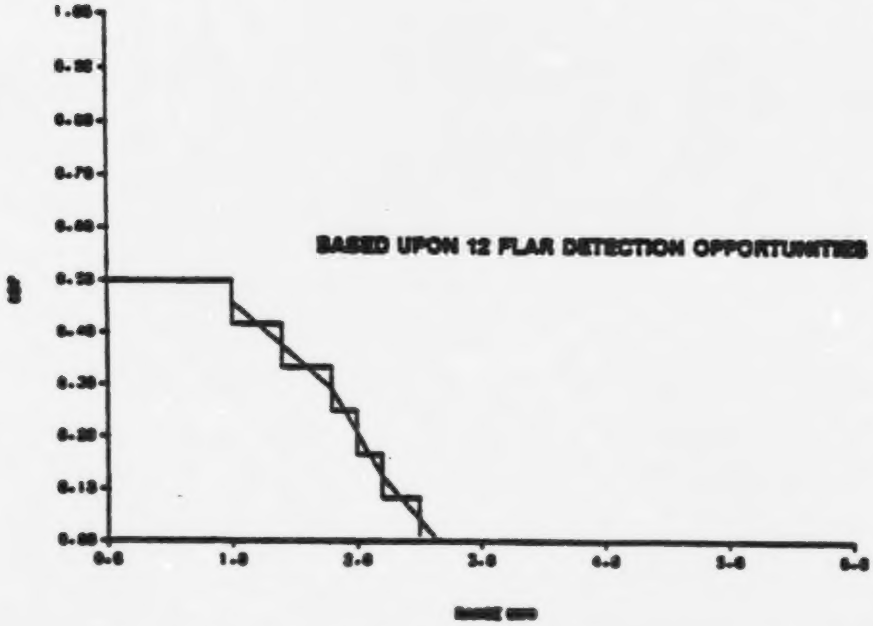


FIGURE 3.48 CDP VERSUS RANGE FOR AN/APS-127 SEARCHING FOR 16-FOOT BOATS WITH RADAR REFLECTORS (1.5-FOOT SEAS)
(Ketchen et al, 1983)

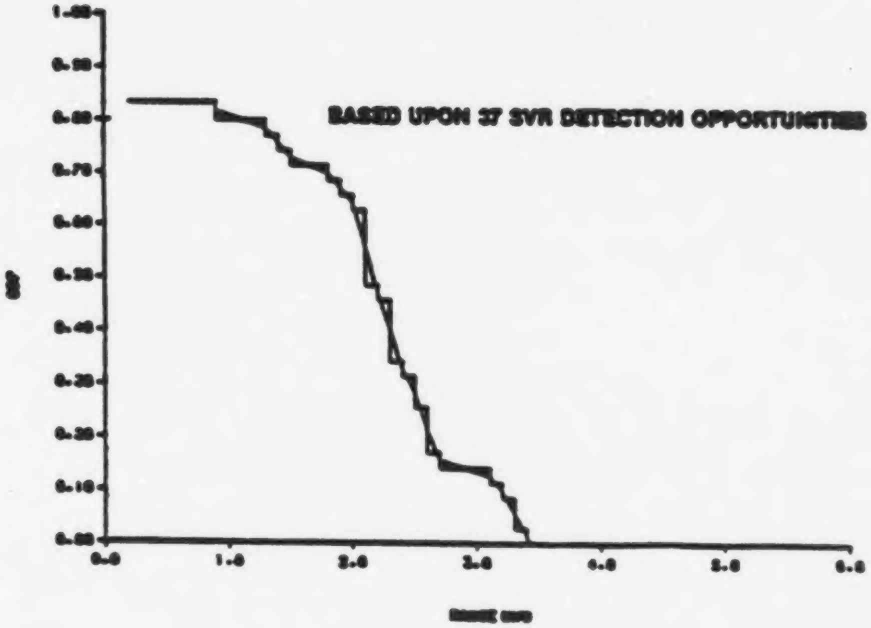


FIGURE 3.49 CDP VERSUS RANGE FOR AN/SPS-64(V) SEARCHING FOR SMALL BOATS AND LIFE RAFTS WITH RADAR REFLECTORS (0- TO 2-FOOT SEAS)
(Ketchen et al, 1983)

TABLE 3.40

SORTED RAW DATA
(Coast Guard Field Tests)
(Ketchen et al, 1984)

FLAR SYSTEM AND OPERATING MODE	SEA STATE	SMALL TARGETS WITH RADAR REFLECTOR			SMALL TARGETS WITHOUT RADAR REFLECTOR		
		No. Detected/ Total	Percent Detect.	Mean Detection Range	No. Detected/ Total	Percent Detect.	Mean Detection Range
APS-127 HDG. STAB. MODE	1	12/20	60	2.8	14/27	52	2.2
	2	14/33	42	2.4	8/22	36	2.4
	3	1/4	25	2.2	6/54	11	2.6
APS-127 GND. STAB. MODE	1	16/20	80	4.4	5/10	50	4.5
	2	24/37	65	5.0	8/18	44	3.0
	3	2/7	29	2.4	0/7	0	–
APS-133 MAP-1 MODE	1	22/24	92	4.2	12/12	100	3.9
	2	30/65	46	3.3	11/31	35	2.8
	3	0/3	0	–	0/3	0	–
APN-215 SRCH.-1 OR SRCH.-2 MODE	1	27/33	82	3.6	18/25	72	2.5
	2	22/42	52	3.5	8/15	53	1.9
	3	0/6	0	–	0/5	0	–

TABLE 3.41

FLAR SYSTEM PERFORMANCE COMPARISONS
(Present Coast Guard FLARs)

(Ketchen et al, 1984)

SYSTEMS COMPARED	SEA STATE 1	SEA STATE 2
APS-127 GND. STAB./SHORT PULSE MODE VS APS-127 HDG. STAB./SHORT PULSE MODE	GND. STAB./SHORT PULSE • Achieved significantly longer detection ranges.	GND. STAB./SHORT PULSE • Achieved sigificantly longer detection ranges. • Detected a significantly higher percentage of targets.
APS-133 MAP-1 MODE VS APS-127 HDG. STAB./SHORT OR LONG PULSE MODE	APS-133 • Achieved significantly longer detection ranges. • Detected a significantly higher percentage of targets.	APS-133 • Achieved significantly longer detection ranges.
APN-215 SRCH.-1 OR SRCH.-2 MODE VS APS-127 HDG. STAB./SHORT OR LONG PULSE MODE	APN-215 • Achieved significantly longer detection ranges. • Detected a significantly higher percentage of targets.	NO SIGNIFICANT DIFFERENCES
APS-127 GND. STAB./SHORT PULSE MODE VS APS-133 MAP-1 MODE	APS-133 • Detected a significantly higher percentage of targets.	APS-127 • Achieved significantly longer detection ranges. • Detected a significantly higher percentage of targets.
APS-127 GND. STAB./SHORT PULSE MODE VS APN-215 SRCH.-1 OR SRCH.-2 MODE	APS-127 • Achieved significantly longer detection ranges.	APS-127 • Achieved significantly longer detection ranges.
APS-133 MAP-1 MODE VS APN-215 SRCH.-1 OR SRCH.-2 MODE	APS-133 • Achieved significantly longer detection ranges. • Detected a significantly higher percentage of targets.	NO SIGNIFICANT DIFFERENCES
SUMMARY	• APS-133 detected highest percentage of targets. • APS-127 (GND. STAB.) and APS-133 consistently outperformed other system/mode combs. • APN-215 outperformed APS-127 (HDG. STAB.).	• APS-127 (GND. STAB.) consistently outperformed all other systems.

DETERMINED BY ANALYSIS OF VARIANCE AT THE .10 LEVEL OF SIGNIFICANCE OR BETTER

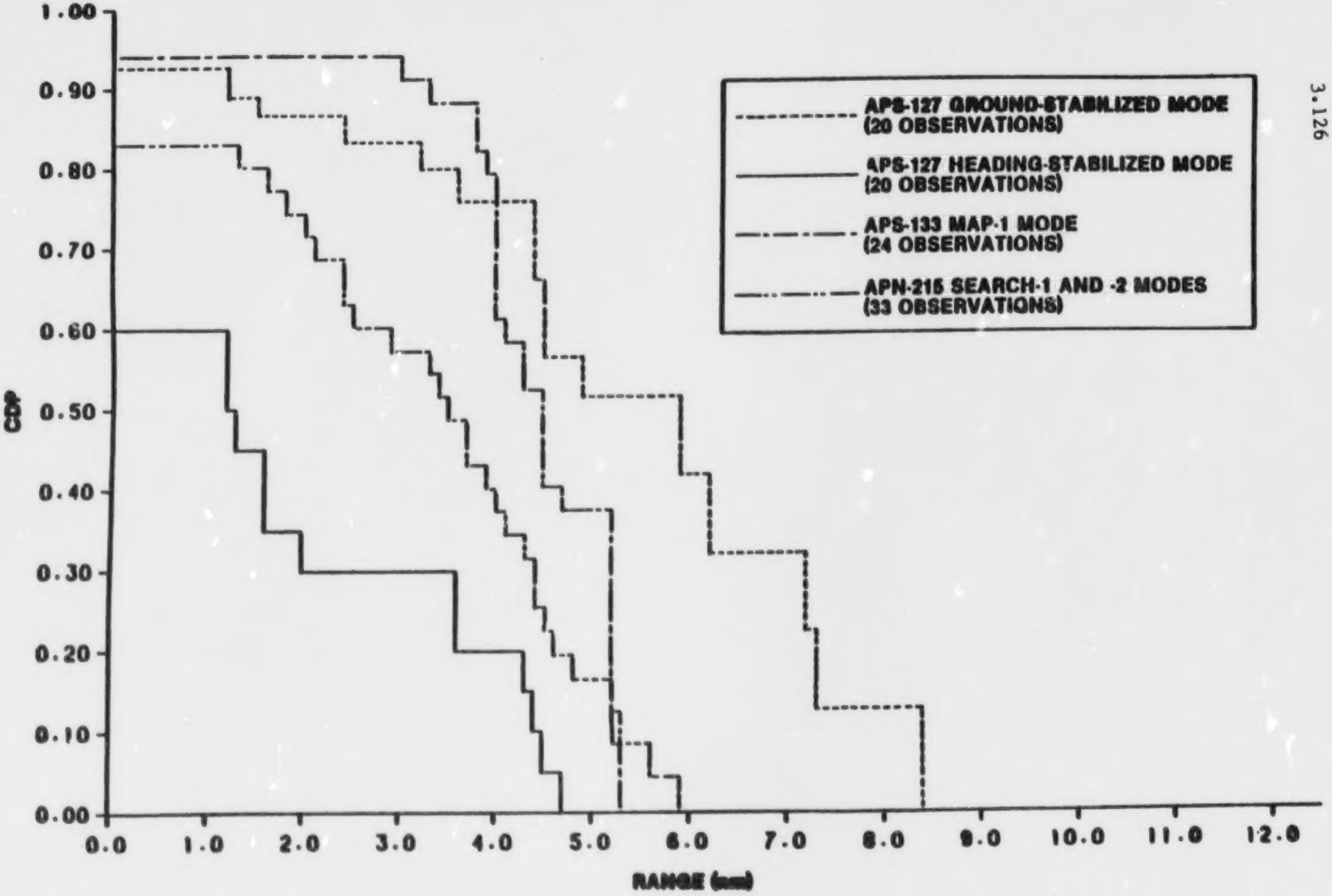


FIGURE 3.50 CDP CURVES FOR TARGETS WITH RADAR REFLECTORS; SEA STATE 1
(Coast Guard Field Tests)

(Ketchen et al, 1984)

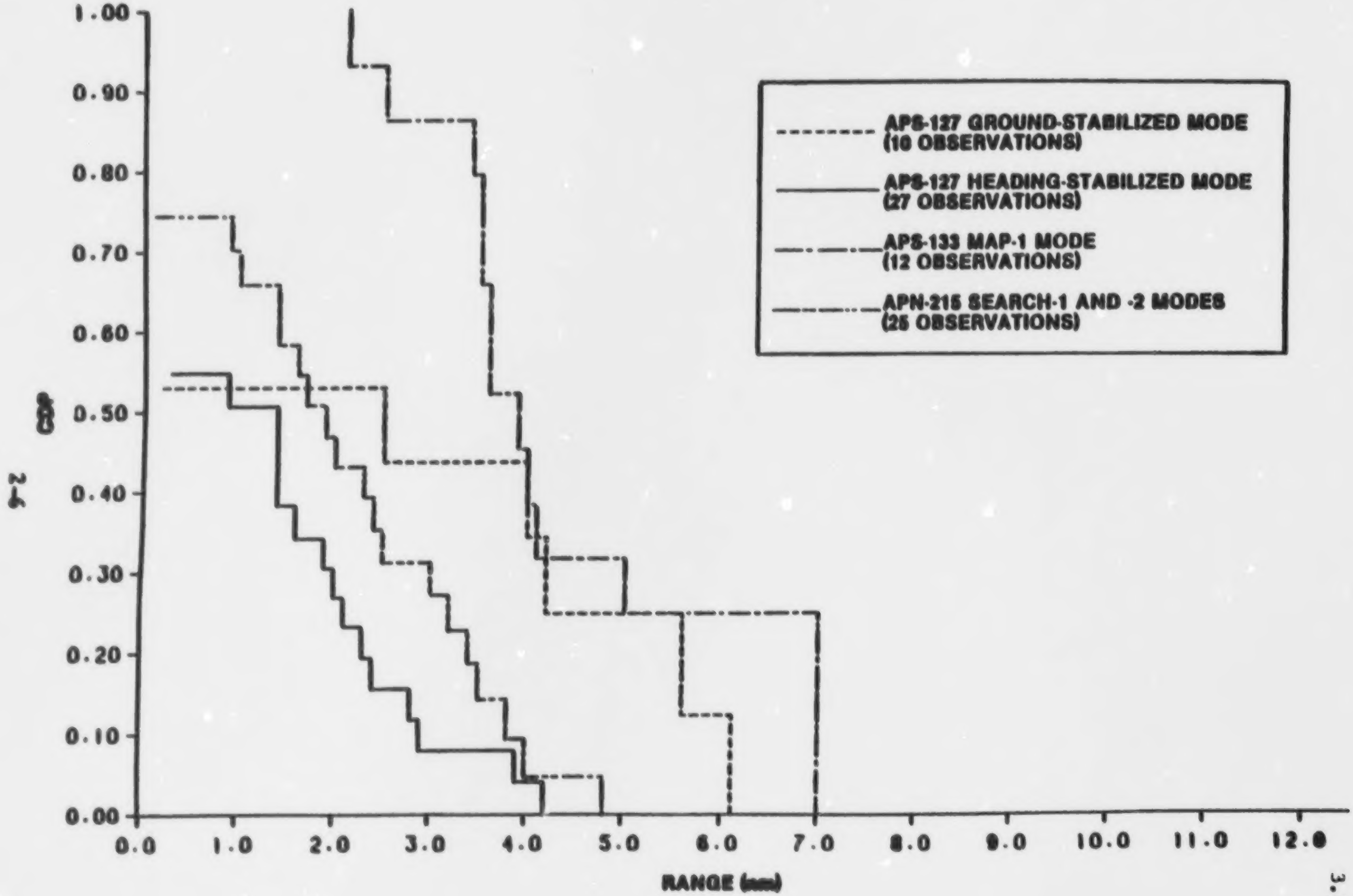


FIGURE 3.51 CDP CURVES FOR TARGETS WITHOUT RADAR RELECTORS; SEA STATE 1
(Coast Guard Field Tests)

(Ketchen et al, 1984)

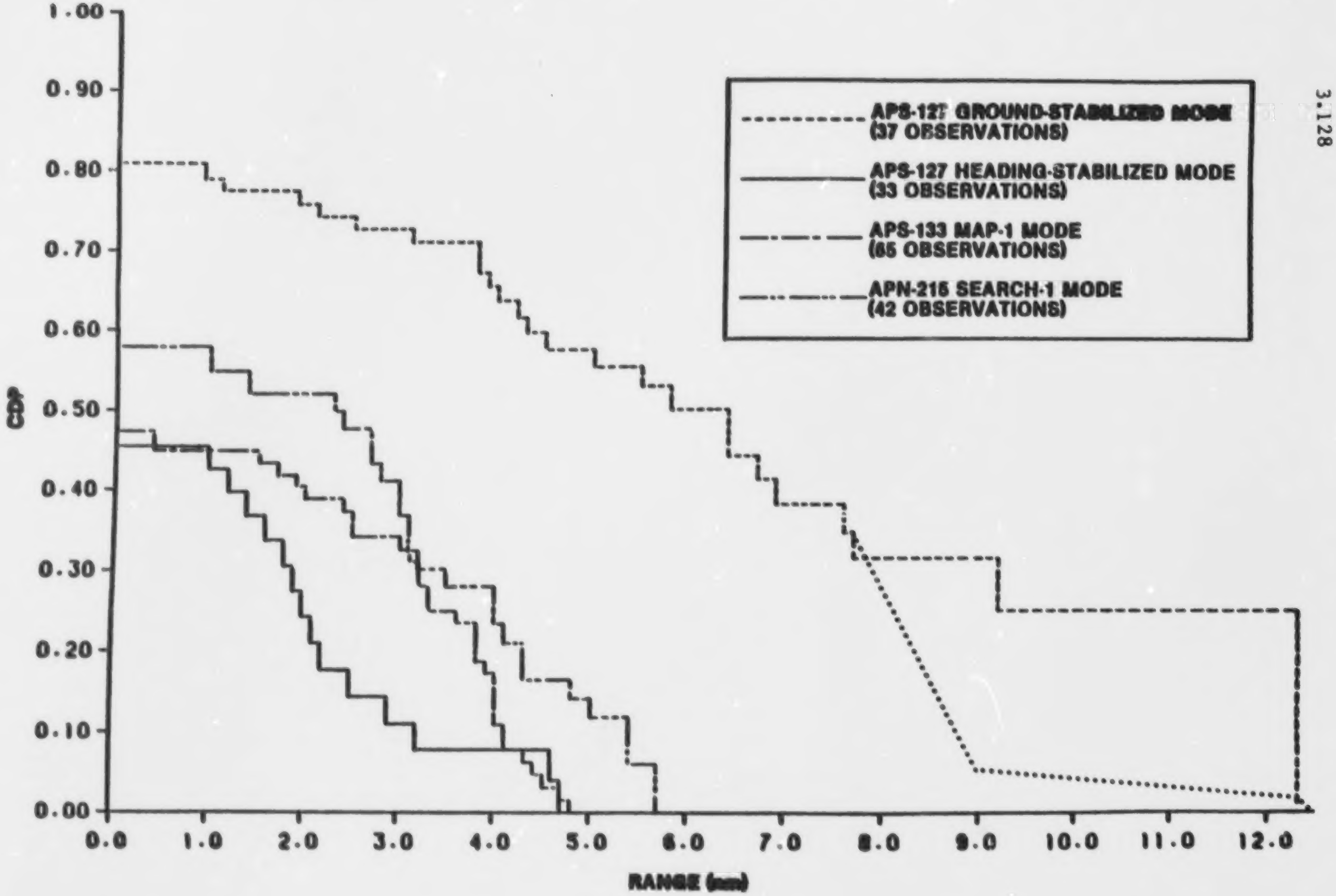


FIGURE 3.52 CDP CURVES FOR TARGETS WITH RADAR REFLECTORS; SEA STATE 2
(Coast Guard Field Tests)
(Ketchen et al, 1984)

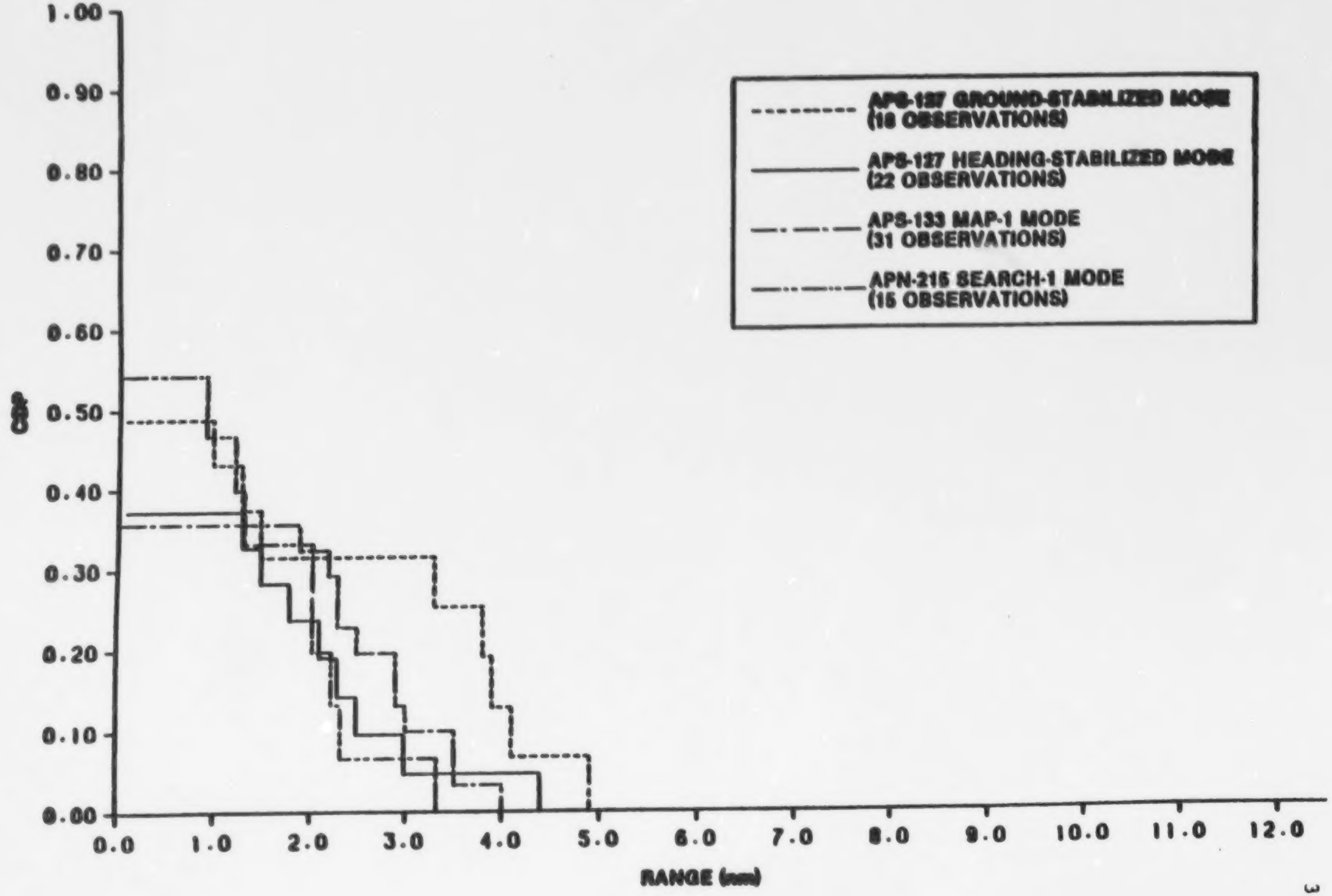


FIGURE 3.53 CDP CURVES FOR TARGETS WITHOUT RADAR REFLECTORS; SEA STATE 2
(Coast Guard Field Tests)

(Ketchen et al, 1984)

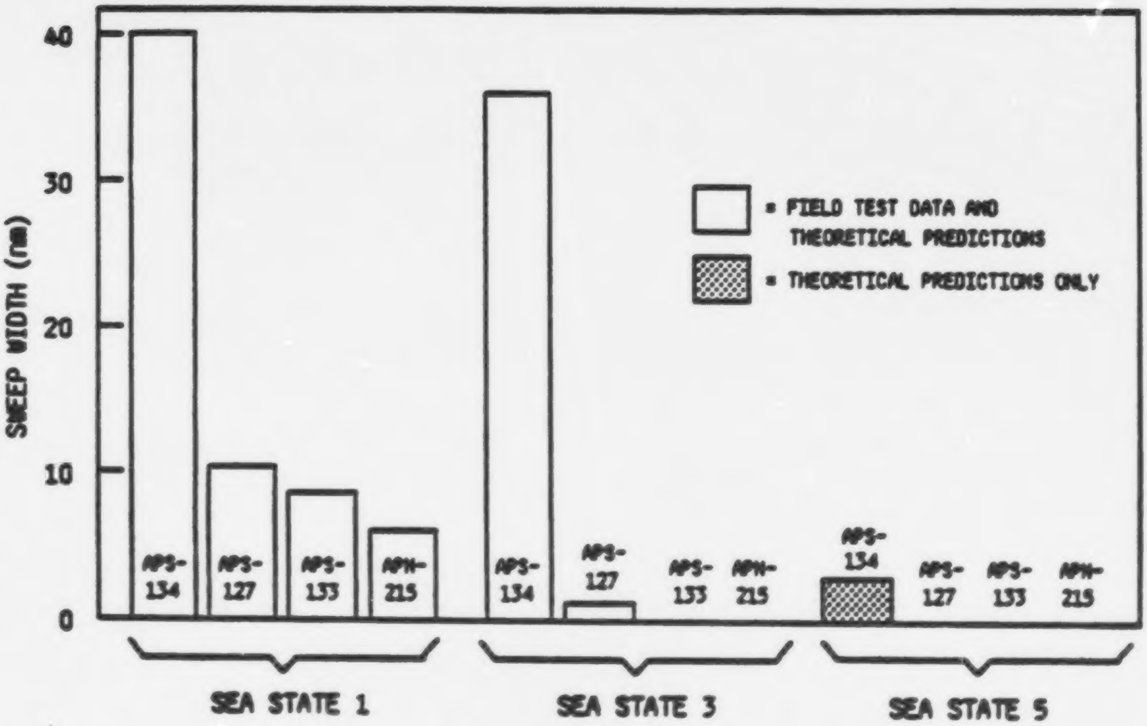


FIGURE 3.54 FLAR SWEEP WIDTHS FOR 1-M^2 TARGETS

(Ketchen et al, 1984)

regarding classification of targets. The authors devised a scenario for FLAR detection and classification. Table 3.42 gives the results of this scenario. Figure 3.55 shows the comparison between visual and two FLAR systems for sea state 1 and Figure 3.56 gives this information for sea state 3, for targets with a radar cross-section of 1 m^2. Figure 3.57 shows the data for a radar cross-section of 100 m^2.

3.2.3 Other Radar Systems

3.2.3.1 Synthetic Aperture Radars

No directed search and rescue tests for synthetic-aperture radars were found in the literature review. As these systems are high resolution relatives of SLARs, it is anticipated that at least similar results would be obtained. A study by Porter and Young (1980) was concerned with the detection of large vessels and is discussed in the section regarding radar satellites.

3.2.3.2 Passive Microwave (Millimeter Radars)

No search and rescue tests were identified in the literature search for these systems. Passive microwave imagers measure the inherent electromagnetic energy given off by the earth's surface and objects on the surface. They have been used extensively for ice mapping and pollution studies. The system on the AOSS has been used to detect icebergs but the U.S.C.G. has not used it for small object detection. Resolutions are relatively poor compared to visual sensors, but because these systems look vertically, they would look at scenes comaprable with line scanners and vertical-looking televisions.

3.3 Satellite Systems

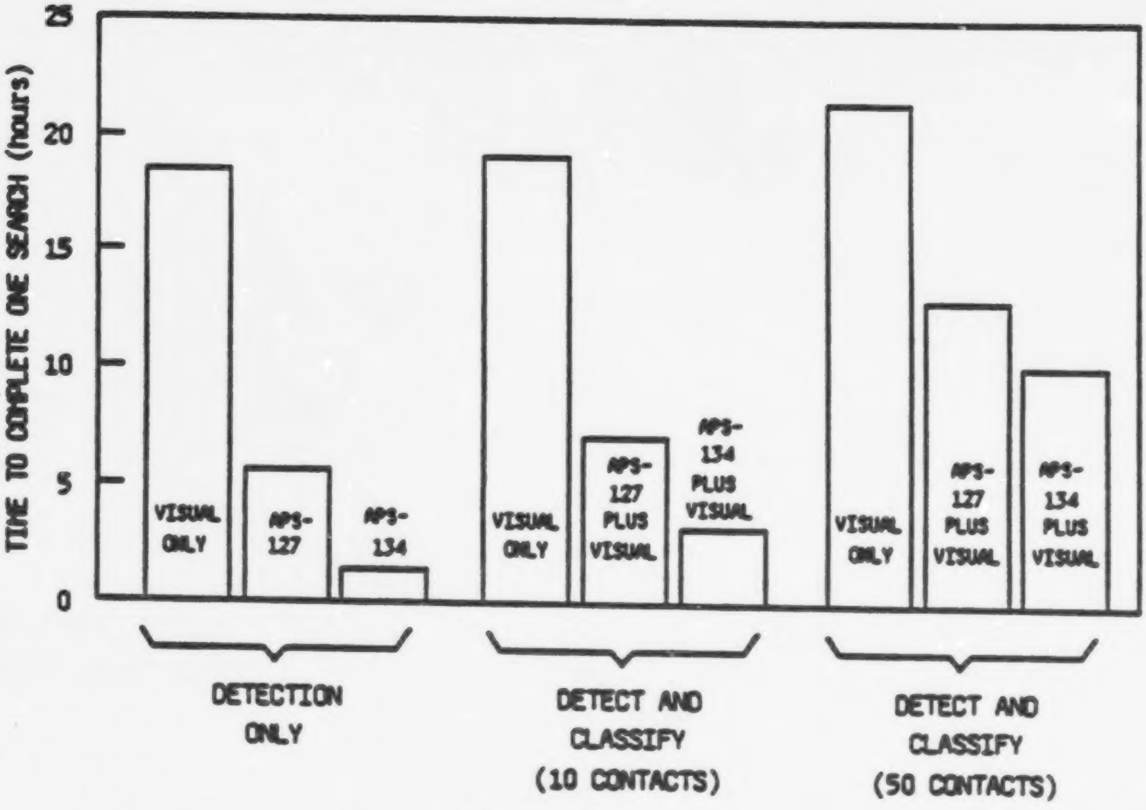
3.3.1 General

Satellite-aided search and rescue is a much-talked-about concept that has shown promise and use with respect to data transmission and platform location (DTPL) categories of satellites, but limited success with the remote sensing categories of satellites. Satellites have been proven to aid search and rescue by providing listening coverage for distress signals over large areas of the earth's surface. These 'radio' satellite systems can provide alerting services through essentially instantaneous notification of distress signals from low power

TABLE 3.42

PREDICTED TIME FOR FLAR-EQUIPPED AIRCRAFT TO COMPLETE ONE SEARCH OF A 75-nm x 75-nm AREA
(1-m^2 target)*
(Ketchen et al, 1984)

FLAR TYPE	SEA STATE (Douglas)	TIME TO COMPLETE (hours)			
		DETECTION ONLY		DETECT AND CLASSIFY	
		VISUAL**	FLAR	10 CONTACTS	50 CONTACTS
APN-215	1	18.4	9.4	10.6	15.7
APS-133	1	18.4	6.7	8.2	13.9
APS-127	1	18.4	5.6	7.1	13.0
APS-134	1	18.4	1.4	3.2	10.1
APN-215	3	55.9	—	55.9	55.9
APS-133	3	55.9	—	55.9	55.9
APS-127	3	55.9	~56	55.9	55.9
APS-134	3	55.9	1.7	3.5	10.4



*COVERAGE FACTOR = 2.0: RADAR CROSS SECTION = 1 m^2

FIGURE 3.55 TIME TO COMPLETE ONE SEARCH OF A 75-NM x 74-NM AREA FOR A 16- TO 18-FOOT WHITE BOAT (Sea State 1)
(Ketchen et al, 1984)

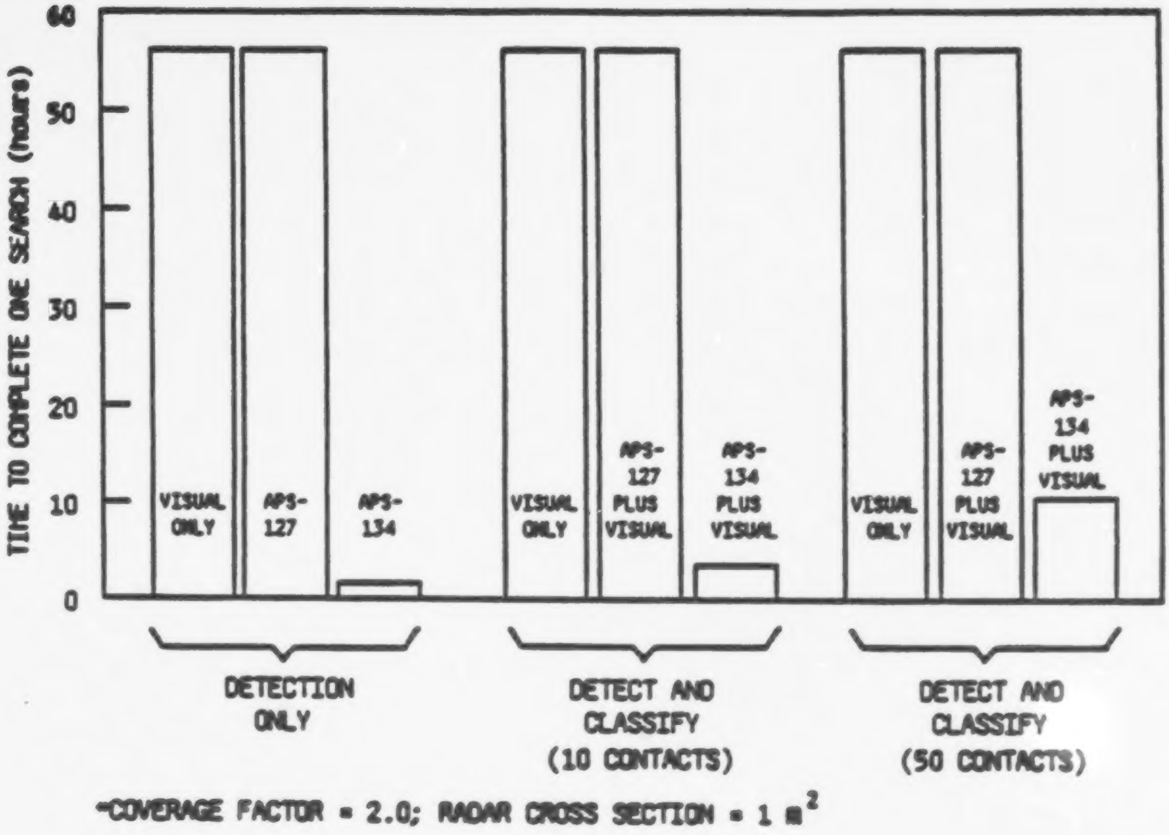


FIGURE 3.56 TIME TO COMPLETE ONE SEARCH OF A 75-NM x 75-NM AREA FOR A 16- TO 18-FOOT WHITE BOAT (Sea State 3)
(Ketchen et al, 1984)

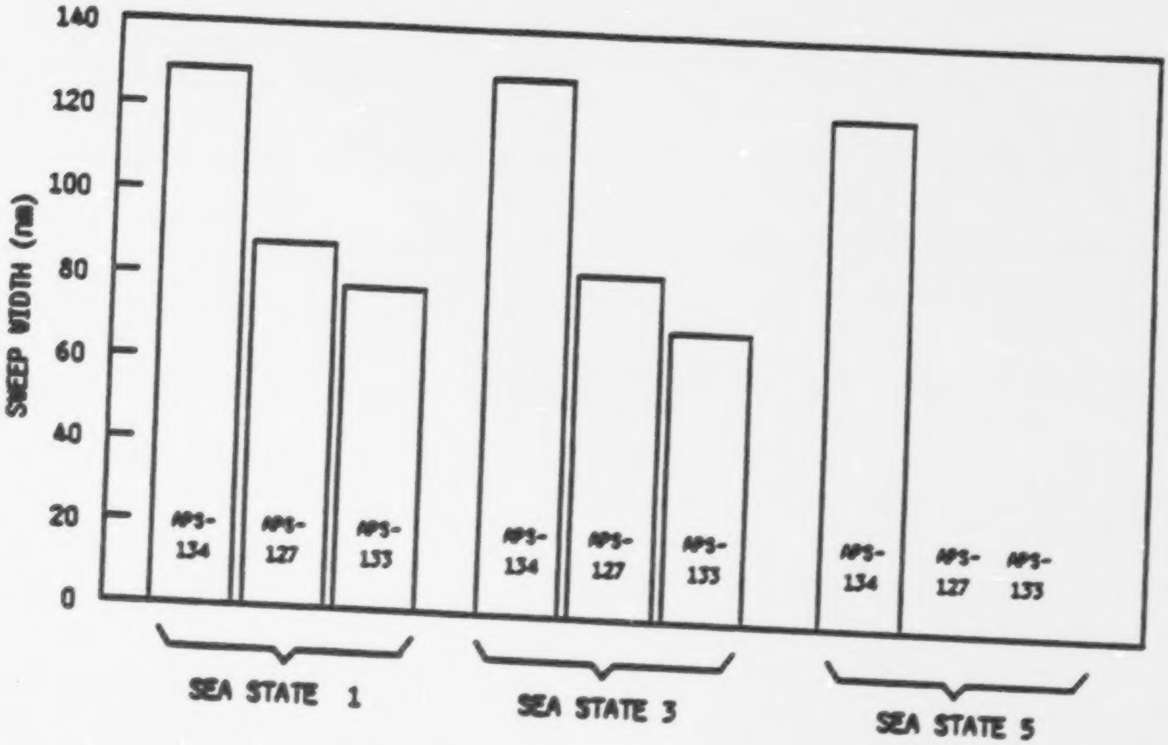


FIGURE 3.57 FLAR SWEEP WIDTHS FOR 100-M^2 TARGETS (Ketchen et al, 1984)

ELT and EPIRB transmissions. They provide position location services using navigational signals coupled with the ELTs and EPIRBs. 'Radio' satellites can also provide useful support to vector and coordinate rescue forces by means of voice communication, and collection and dissemination of environmental data.

The DTPL is the less glamorous side of satellite technology, but in terms of search and rescue it has been far more successful than the remote sensing satellite technology. This has been mainly because the remote sensing type systems have been hampered by cloud cover in the case of visual/optical sensors and by the fact that most ocean surface processes occur below the sea surface which is unaccessible to remote sensing sensors. This has especially hampered the collection of environmental data which are need in search and rescue.

3.3.2 Visual/Optical Satellites

A study by McDonnell and Lewis (1978) showed that ship detection using LANDSAT imagery was possible. This study showed that the MSS Band 7 provided the best detection capability. This was due to the low radiance values from the water in this spectral wavelength region and resultant high signal-to-noise ratios in the comparison of vessels to water backgrounds. The study showed that ship size, orientation, state of motion and direction of movement could be determined. The study pointed out the major drawbacks of the use of LANDSAT imagery. The conclusion of the study was that in wider, low-turbidity conditions (characteristic of open seas), ships greater than 100 m could be identified. The study theoretically showed that ship detection down to 30 m was possible. High turbidity such as would be found close to shore or close to the mouths of major river systems inhibits ship detection by decreasing the S/N ratio. The study also concluded that wake detection depended on solar elevation angle and sea state.

A report in "Aviation Week and Space Technology" (1983) discussed the use of LANDSAT to monitor Soviet rescue missions in arctic sea ice. This study showed that ship paths in ice could be identified. Actual detection of ships appeared to be accomplished only by identifying the end of the ice trail. The study, although not reported in technical detail, appeared to conclude that the actual ships were not detectable. In addition, ice cover was 100%, which is a situation different than the environmental constraints of the study.

A study by Ochiai and Tsuchiya (1981) was concerned with the use of LANDSAT and NOAA satellite visual/optical sensing systems for the detection of sea surface phenomena. The study showed that basic environmental phenomena could be measured, particularly tidal fronts and sea surface temperature data. No attempt was made by the study to concern itself with small object detection.

3.3.3 All-Weather Satellites

Sivertson et al (1977) reported a series of studies leading up to a space shuttle search and rescue experiment using synthetic- aperture radar. Feasibility of using synthetic aperture radar was reported paricularly by the use of passive radar reflectors. The program was mainly concerned with establishing the proof of concept. The basic concept was concerned with the development of the use of passive radar reflectors in conjunction with side-looking radar (in this case, synthetic-aperture) to detect, identify and locate the position of search and rescue targets. The concept is concerned with the design of the radar reflector and not with the detection of small objects. It assumes that the reflector must be needed and it assumes that the radar system should be space-borne. The study reported on use of a synthetic aperture radar experiment over land. The most important concepts presented were the portable radar reflectors.

In a study by Porter and Young (1980), Canadian tests on human activities on the ocean as part of the SURSAT project were reported. The objective of the study was to assess the capability of a satellite borne synthetic aperture radar to detect, locate, and classify marine targets for surveillance and traffic management. The study utilized the CCRS synthetic aperture radar systems to collect data for assessment of data potential for a space-borne radar system. Although only a limited experiment, the study showed that ship detection was potentially possible. The investigators found that ship motion, particularly velocity in the azimuth direction, degrades synthetic aperture image quality; that increasing sea clutter is significant in decreasing the probability of ship detection; that ship detection is not dramatically improved by processing the radar data to the highest resolution; and that no strong dependence on radar parameters of frequency, polarization, and depression angle were observable.

Gower (1982) discussed satellite remote sensing with respect to fisheries applications. A large part of this paper was concerned with all-weather sensing systems. The results are mainly applicable to environmental conditions and various means to measure them, synthetic aperture radar, scatterometers, microwave radiometers and radar altimeters.

3.3.4 SARSAT

Search and Rescue Satellite (SARSAT), in current use, has successfully located down targets with ELTs and EPIRBs that are activated due to crash. The development aspects of the program are complete and the system is basically operational. Although the system is basically satellite controlled, the same notification and homing signals can be picked up by aircraft. This provides a second dimension to 'radio' oriented search and rescue. The system has proven useful and will not be part of this evaluation as it is now an operations method (Werstruk, 1983).

3.4 Search Patterns

Various flying patterns were used by the USCG to obtain data for evaluation (Osmer et al, 1981; Edwards et al, 1980b). For actual searches as per a search and rescue mission, two basic patterns are used: parallel (Figure 3.58) and creeping line (Figure 3.59). Parallel searches involve a series of flight lines flown in the direction of the major axis of the search area. The separation between lines is delineated by a specific track spacing. Creeping line searches are carried out perpendicular to the major axis of the search area, or parallel to the minor axis. Line separation is delineated by a specified track spacing. These two patterns are basic to search and rescue techniques and applicable to good human observer performance. The

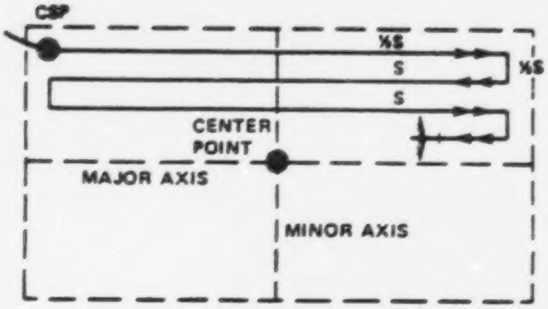

CSP
½S
S
S
½S
CENTER POINT
MAJOR AXIS
MINOR AXIS

FIGURE 3.58 PARALLEL SEARCH PATTERN (Edwards et al, 1980b)

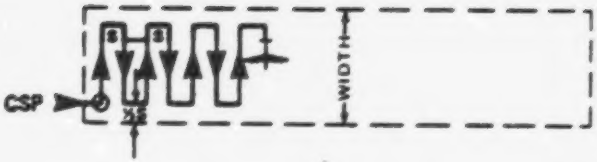

S
S
CSP
½S
WIDTH

FIGURE 3.59 CREEPING LINE SEARCH PATTERN (Edwards et al, 1980b)

lines can be skewed such as in the case when LORAN is used. In this case, search is along LORAN lines or, in the case of TACAN, along arcs of constant range (Figures 3.60 and 3.61). SLAR flight patterns coincided with parallel and creeping line search tracks, but also included two other patterns that could be flown for collection of data, for post-flight data collection: the box pattern (Figure 3.62) and the fly-by pattern (Figure 3.63). The box pattern consists of flying around the boundaries of a search area parallel to the boundaries with turns made away from the search area. The fly-by pattern involves a series of track line searches, or fly-bys, past a target array. The fly-bys are flown at increasing range to maximum detection range, thus maximizing data collection.

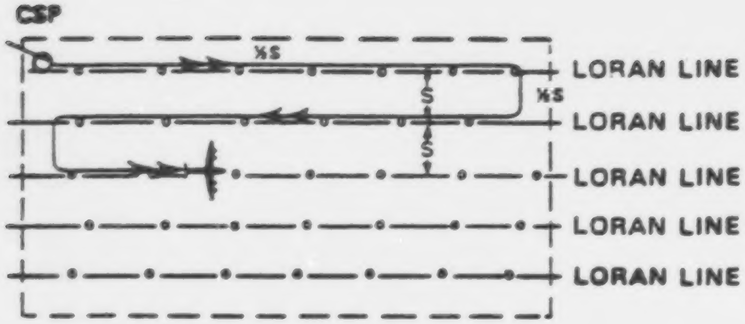

CSP
½S
S
½S
S
LORAN LINE
LORAN LINE
LORAN LINE
LORAN LINE
LORAN LINE

FIGURE 3.60 CUTTER AND FIXED WING AIRCRAFT SEARCH PATTERN (Edwards et al, 1980b)

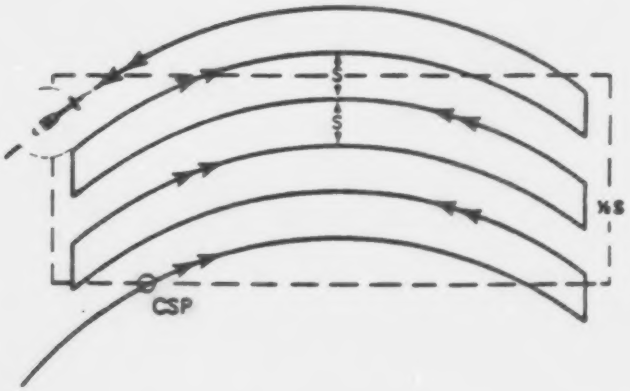


FIGURE 3.61 HELICOPTER SEARCH PATTERN (Edwards et al, 1980b)

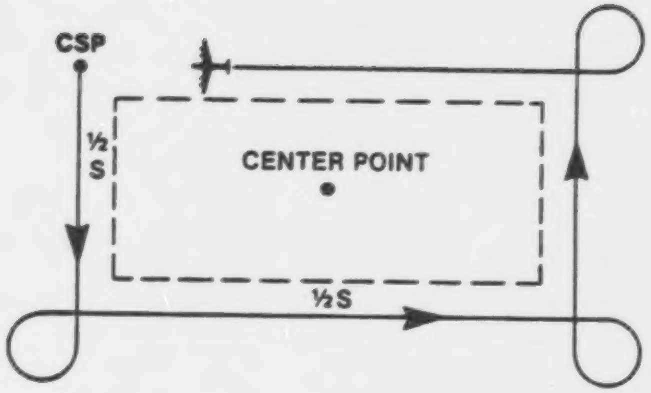

CSP
½
S
CENTER POINT
½S

FIGURE 3.62 BOX PATTERN
(Edwards et al, 1980b)

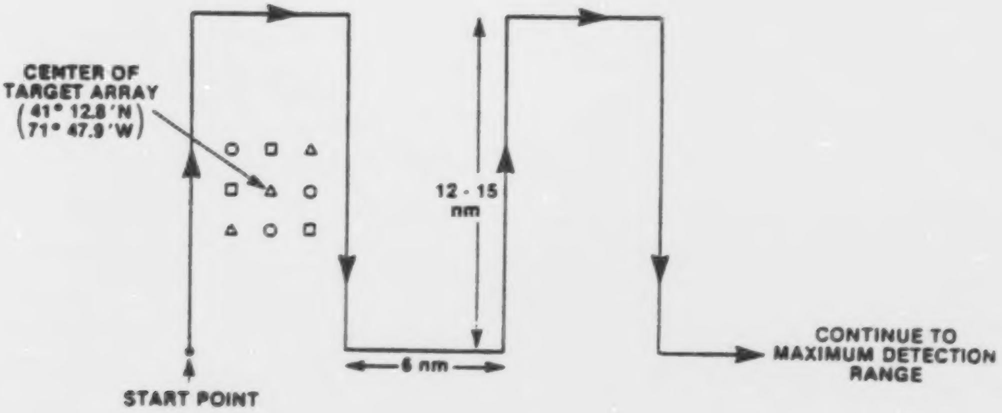

CENTER OF
TARGET ARRAY
(41° 12.8′N
71° 47.9′W)
12 - 15
nm
6 nm
START POINT
CONTINUE TO
MAXIMUM DETECTION
RANGE

FIGURE 3.63 FLY-BY PATTERN
(Edwards et al, 1980b)

CHAPTER 4

DISCUSSION

4.1 Environmental Considerations

The studies carried out by the U.S.C.G. are basically fair-weather studies. The extreme conditions that occur in Canadian waters do not occur in U.S. waters. Therefore, in terms of environmental parameters, U.S.C.G. small object detection data cannot truly be extrapolated to the Canadian situation, although the data trends are valid.

In terms of sea surface temperature, extreme cold occurs from January to March. The U.S. data was never tested in water conditions where ice can form. These extreme cold conditions would probably have their most noticeable effect on the target-to-background or signal-to-noise (S/N) ratios for infrared detection. The extreme cold water also provides freezing spray conditions which could also have an effect on detection probabilities.

U.S.C.G. data appear to be for only two wave height conditions: 0 - 2 m, and greater than 2 m. On the Grand Banks, the proposed study area, waves can exceed 10 m. For study purposes, three qualitative wave regimes with quantitative limits are proposed: 0 - 2 m (calm), 2 - 4 m (moderate) and 4 - 10 m (rough). Sea states greater than 10 m are extreme and will most likely not be encountered during any test study. The range of required sea states is most likely to occur from January to March. The P(x) data generated to date and discussed in the report shows that the complex relationship between waves and wind has basically been ignored. Both have been treated as independent variables, although there are environmental periods when they strongly affect each other. January through March is the period of extreme wind potential. As this is the period of highest expected wave height conditions, more information may be derived concerning the dependency/interdependency of these two variables.

Currents should have no effect on any test study, except for localized current forces that may result in irregular drift by any test targets.

The general term 'weather' involves many different parameters. Air temperature and pressure should have no significant effect on P(x), as shown by U.S.C.G. studies, yet the period from January to March offers the most extreme conditions for these two variables. Therefore, if any effect is to occur, it will probably be under these extreme conditions. Precipitation is probably the most important variable in terms of sensor performance. The presence of precipitation can cause a degradation in performance of all sensors with potential use in a small object detection suite. The extreme forms of precipitation; rain, mist, snow, sleet, hail, rime and freezing rain can all occur from January to March. Visibility is the second most important parameter in terms of sensor performance. It is mainly important for visual detection for both the human observer and the electro-optical sensors. January to March presents periods of overcast, obscured skies, chance of fog and reduced visibility, while June to August presents periods of extreme conditions, either very clear or high fog potential.

Operational weather is at its worst from January to March. Although visibility is somewhat better than in the summer, ice conditions occur and the 'good weather' conditions of visibility greater than 2 nm and winds less than 25 kts occur approximately 40% of the time. These conditions will allow a reasonable amount of good weather during a January-to-March test to set and retrieve test targets.

Sea ice could be a problem in the areas during the proposed study period. As previously stated, ice in concentrations less than 1/10 represent false alarm targets. Ice concentrations greater than 1/10 represent pack ice, which is not within the terms of reference of this study as the target background being considered is the ocean, not ice.

Icebergs will be present during the proposed study; these will also be be false alarm targets. The mean historical limit passes through the proposed study area in March, but the quantity of bergs should still be low at that time of year.

For environmental considerations, January to March represents the worst and most extreme conditions. A test carried out during this time period will add a new dimension to USCG studies and provide data under uniquely Canadian conditions.

4.2 Targets

The evaluations carried out by the U.S.C.G. basically agree with the target size classes outlined in Section 2.2. PIWs are targets less than 1 m. The life rafts and life boats fall into the range of 1 - 5 m, the 41' boats into the range of 5 - 15 m, and all other vessels into the class larger than 15 m. Any future testing should include targets in each of these size classes. P(x) can then be determined by size range, and internal comparisons based on target composition can be carried out.

In any test, within each size range, detection aids should be used on some targets; U.S.C.G. studies recommend looking into placing radar reflectors on some targets and not on others. Other aids that should be considered are lights, flares and reflection tape for visual detection category sensors; and radar reflectors, active radar transponders and passive ballon-type radar reflectors that can be raised above the wave surface. A variety of these aids should be situated in any test area.

The problem of false alarm targets is difficult to deal with. Animal life, sea ice and icebergs transgress all size categories. Artifacts caused by the ocean surface can also be a problem. It is felt by the evaluators that the most important concept in small object detection is the establishment, in some way, of a characteristic signature. This may not be completely possible in one experiment, but may be possible by re-evaluating U.S.C.G. data in terms of new methodologies developed in this proposed study. To assist in establishing characteristics signatures, and to reduce the possibilities of false alarm, it is proposed that all test targets be moored either separately or in arrays. This will basically fix the targets to some reference point. False alarm targets will then be identified by their movement or subsequent absence in successive search passes.

The zone or range from zone concept is valid to some extent if targets are set in the zones. This is especially important with respect to the test program that will be proposed in a subsequent section. Two study sites will be proposed: one near shore in a large enclosed bay, and the other offshore, probably on the Grand Banks near the drill ships in the Hibernia area. The large bay will include three of the zones: 0 - 3 nm, 3 - 12 nm, and 12 - 50 nm. The second area will encompass the fourth zone, greater than 50 nm. Thus, for the first proposed test area, position of targets will be important.

4.3 Search and Rescue Concepts

The evaluators would like to introduce a major point concerned with the concept of sweep width. Figure 2.54a shows the graphic presentation of sweep width for visual observation and Figure 3.21 shows the graphic presentation for SLAR. A normalization type process is carried out whereby targets within the sweep width but not detected are equated with targets that are detected outside the sweep width. Note that for visual observations, P(x) at 0 range is slightly decreased and P(x) for SLAR at 0 range is zero because of the delay space below the aircraft. With respect to the use of electronic sensors, they may not always be positioned so they can search the area directly below the aircraft. This raises the question "Is a target not detected if the opportunity does not exist for it to be detected?". In other words, targets that do not fall within the field of view of the sensor are not valid opportunities for detection. If they are not valid opportunities, then they cannot be classified as not detected. This means that sweep width must be re-evaluated in terms of the capabilities of each sensor used and may result in sweep width not being a valid measurement parameter. A flexible or adjustable sweep width may be necessary.

In the case of forward looking sensors, the FLIR and FLAR, the U.S.C.G. did not use sweep width because the concept is basically invalid in this case. For detection, both these sensors require the accumulation of hits or detections to verify the presence of a target. Thus, P(x) is really a cumulative detection probability (CDP) that increases to a limit as range closes. To ascertain coverage, the concept of detection envelop as used with marine radar detection is brought forth. The width of the detection envelope should be suitable for the development of a pseudo sweep width once enough statistics are accumulated. In addition, P(x) can be derived for CDP data. When the upper limit of detection is reached, the upper flat part of Figure 3.45, where sea/ground clutter dominates, is really a detection probability under specific conditions. It may be possible to develop P(x) relationships once data samples become statistically valid.

The U.S.C.G. concepts of track spacing (S), probability of detection (P), sweep width (W) and coverage factor (C) are valid. All new methods and sensors should be tested and worked with these concepts. The development of single number representations is the simplest concept in engineering terms and reduces the possibility of error, removing the results of chance from the operations. The full development of each acceptable sensor for small object detection in terms of human observer methodology should be pursued. This development should be extended to the correction factor and nomograph stage if possible.

Observer effectiveness should also be examined. Tests have been carried out with human observers acting as sensors. No tests have been undertaken with respect to the observer watching a video screen or some other data output device. Post-flight analysis with FLIR has shown some improvement in detection probability. This improvement should be further quantified and comparisons made with human operators and human observers.

EPIRBs and ELTs sweep widths are discussed in the search and rescue manual. As this technology is significantly advanced, it will not be discussed in this report.

4.4 Visual Detection

4.4.1 Systems

4.4.1.1 Human Observers

The most extensive work carried out for detecting small objects on an ocean background uses the human observer as the detection system. In this case the eye is the sensor. The bulk of the visual detection performance work is reported in Edwards et al. (1981). Figure 3.8 shows the data for helicopter platforms for 16' boats (5 m). It can be seen that the computed lateral range is in the order of 7 nm, while the observed maximum lateral range is approximately 4.5 nm. Conditions were as follows: zero swell height, excellent visibility, and relatively negligible wind speed (5 kts). P(x) rapidly decreases beyond 1 nm. Figure 3.9 shows the effect of sweep width change due to airspeed increase. It should be noted that W changed by 1 nm, which is significant. For lateral ranges less than 1 nm, search speed has no effect, while the higher speeds result in lateral range reductions. To test altitude effects, cumulative detection probability vs. range was plotted (Figure 4.1). This set of curves shows that there is a degradation in aircraft detection performance for ranges less than 1 nm and altitudes greater than 400', and that at higher altitudes the CDP is higher for larger ranges and levels off at closer ranges, and vice versa for lower altitudes. From this data, it would appear that for this class of targets under these environmental conditions, detection is not sensitive for altitudes up to 4000'. The data also serve to indicate that the higher altitudes allow detection at further ranges and decrease detection at closer ranges. This may be due to the slant range geometry and viewing angles. Tables 4.1, 4.2 and 4.3 are sweep width tables prepared from the airborne data for various conditions. These show significant variance for wind speed/swell height combinations, moderate variance due to visibility and cloud cover and moderate variance due to time on task.

Detection for PIWs was degraded compared to 16' boat detection. This can be seen in Figure 3.10. Lateral ranges decreased significantly. Wind speed/swell height and time on task were the most

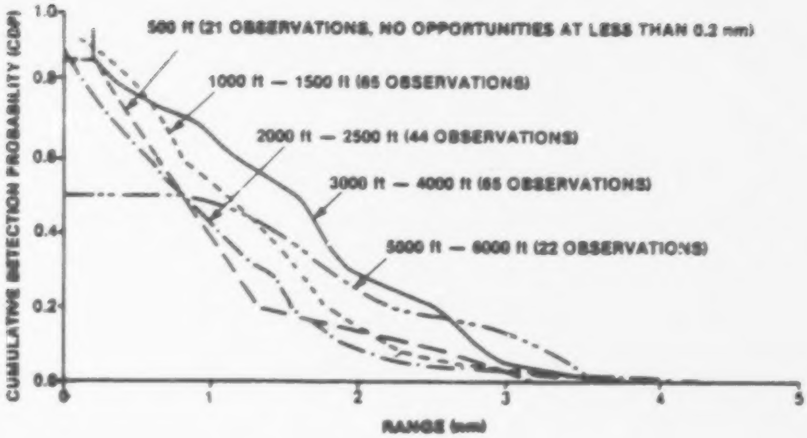


FIGURE 4.1 CUMULATIVE DETECTION PROBABILITY (CDP) VERSUS RANGE FOR ORANGE LIFE RAFTS

(Edwards et al, 1981)

TABLE 4.1

SWEEP WIDTHS FOR HELICOPTERS/FIXED-WING AIRCRAFT SEARCHING FOR WHITE 16-FOOT BOATS OR ORANGE CANOPIED LIFE RAFTS

(Edwards et al, 1981)

VISIBILITY (nm)	CLOUD COVER (tenths)	WIND SPEED/SWELL HEIGHT								
		≤ 10 knots/≤ 1 ft			15 knots/2-3 ft			20-25 knots/4-5 ft		
		Time on Task (hr)			Time on Task (hr)			Time on Task (hr)		
		0-1	1-2	>2	0-1	1-2	>2	0-1	1-2	>2
1	1.0	1.4* 1.1*	1.3* 0.9*	1.2* 0.8*	0.8* 0.4*	0.7* 0.3*	0.6* 0.3*	0.4* 0.2*	0.3* 0.1*	0.3* 0.1*
3	1.0	2.8 2.1*	2.7 1.9*	2.5 1.6*	1.4 0.8*	1.3 0.7*	1.1 0.6*	0.7 0.3*	0.6 0.3*	0.5 0.2*
5	0.0	3.9 3.3	3.6 3.0	3.4 2.7	2.1 1.6	1.9 1.4	1.7 1.2	1.1* 0.7*	1.0* 0.6*	0.9* 0.5*
	0.5	3.6 2.9	3.4 2.6	3.1 2.4	1.9 1.3	1.7 1.1	1.5 1.0	1.0* 0.6*	0.9* 0.5*	0.8* 0.4*
	1.0	3.3 2.5	3.1 2.3	2.9 2.0	1.7 1.1	1.5 0.9	1.3 0.8	0.8* 0.5*	0.7* 0.4*	0.7* 0.3*
≥10	0.0	4.4 4.1	4.2 3.8	3.9 3.5	2.5 2.2	2.3 1.9	2.1 1.7	1.4 1.1	1.3 1.0	1.1 0.8
	0.5	4.1 3.7	3.9 3.4	3.6 3.1	2.3 1.9	2.1 1.6	1.9 1.4	1.2 0.9	1.1 0.8	1.0 0.6
	1.0	3.9 3.3	3.6 3.0	3.4 2.7	2.0 1.5	1.8 1.4	1.7 1.2	1.1 0.7	1.0 0.6	0.9 0.5

*This combination of conditions did not exist in the data base. Sweep width is extrapolated from the LOGODDS model.

TABLE 4.2

SWEEP WIDTHS FOR HELICOPTERS/FIXED-WING AIRCRAFT SEARCHING FOR BLUE 16-FOOT BOATS OR ORANGE LIFE RAFTS WITHOUT CANOPIES

(Edwards et al, 1981)

VISIBILITY (nm)	CLOUD COVER (tenths)	WIND SPEED/SWELL HEIGHT								
		≤ 10 knots/≤ 1 ft			15 knots/2-3 ft			20-25 knots/4-5 ft		
		Time on Task (hr)			Time on Task (hr)			Time on Task (hr)		
		0-1	1-2	>2	0-1	1-2	>2	0-1	1-2	>2
1	1.0	1.1* / 0.7*	1.0* / 0.6*	0.9* / 0.6*	0.5* / 0.3*	0.4* / 0.2*	0.4* / 0.2*	0.2* / 0.1*	0.2* / 0.1*	0.2* / 0.1*
3	1.0	2.1 / 1.5*	1.9 / 1.3*	1.8 / 1.1*	0.9 / 0.5*	0.8 / 0.4*	0.7 / 0.3*	0.4 / 0.2*	0.4 / 0.2*	0.3 / 0.1*
5	0.0	2.9 / 2.5	2.7 / 2.2	2.5 / 2.0	1.4 / 1.0	1.2 / 0.9	1.1 / 0.7	0.7* / 0.4*	0.6* / 0.4*	0.5* / 0.3*
	0.5	2.7 / 2.1	2.5 / 1.9	2.3 / 1.7	1.2 / 0.8	1.1 / 0.7	1.0 / 0.6	0.6* / 0.3*	0.5* / 0.3*	0.4* / 0.2*
	1.0	2.4 / 1.8	2.2 / 1.6	2.0 / 1.4	1.1 / 0.7	0.9 / 0.5	0.8 / 0.5	0.5* / 0.3*	0.4* / 0.2*	0.4* / 0.2*
≥10	0.0	3.4 / 3.2	3.2 / 2.9	3.0 / 2.6	1.7 / 1.5	1.5 / 1.3	1.4 / 1.1	0.9 / 0.7	0.8 / 0.6	0.7 / 0.5
	0.5	3.1 / 2.8	2.9 / 2.6	2.7 / 2.3	1.5 / 1.3	1.4 / 1.1	1.2 / 0.9	0.8 / 0.5	0.7 / 0.5	0.6 / 0.4
	1.0	2.9 / 2.5	2.7 / 2.2	2.5 / 2.0	1.3 / 1.0	1.2 / 0.8	1.1 / 0.7	0.7 / 0.4	0.6 / 0.3	0.5 / 0.3

*This combination of conditions did not exist in the data base. Sweep width is extrapolated from the LOGODDS model.

TABLE 4.3

SWEEP WIDTHS FOR HELICOPTERS/FIXED-WING AIRCRAFT SEARCHING FOR BLACK LIFE RAFTS WITHOUT CANOPIES
(Edwards et al, 1981)

VISIBILITY (nm)	CLOUD COVER (tenths)	WIND SPEED/SWELL HEIGHT								
		≤ 10 knots/≤ 1 ft			15 knots/2-3 ft			20-25 knots/4-5 ft		
		Time on Task (hr)			Time on Task (hr)			Time on Task (hr)		
		0-1	1-2	>2	0-1	1-2	>2	0-1	1-2	>2
	1.0	0.9* 0.6*	0.9* 0.6*	0.8* 0.5*	0.4* 0.2*	0.4* 0.2*	0.3* 0.1*	0.2* 0.1*	0.2* 0.1*	0.1* 0.1*
3	1.0	1.8 1.3*	1.7 1.1*	1.5 0.9*	0.7 0.4*	0.7 0.3*	0.6 0.3*	0.3* 0.2*	0.3* 0.1*	0.2* 0.1*
	0.0	2.6 2.2	2.4 2.0	2.2 1.7	1.2 0.9	1.0 0.7	0.9 0.6	0.6* 0.3*	0.5* 0.3*	0.4* 0.2*
5	0.5	2.4 1.9	2.2 1.7	2.0 1.4	1.0 0.7	0.9 0.6	0.8 0.5	0.5* 0.3*	0.4* 0.2*	0.4* 0.2*
	1.0	2.2 1.6	2.0 1.4	1.8 1.2	0.9 0.5	0.8 0.5	0.7 0.4	0.4* 0.2*	0.3* 0.2*	0.3* 0.1*
	0.0	3.1 2.9	2.8 2.6	2.6 2.4	1.5 1.3	1.3 1.1	1.2 0.9	0.7 0.6	0.6 0.5	0.6 0.4
≥10	0.5	2.8 2.5	2.6 2.3	2.4 2.0	1.3 1.1	1.2 0.9	1.0 0.8	0.6 0.5	0.6 0.4	0.5 0.3
	1.0	2.6 2.2	2.4 2.0	2.2 1.7	1.1 0.9	1.0 0.7	0.9 0.6	0.5 0.4	0.5 0.3	0.4 0.2

*This combination of conditions did not exist in the data base. Sweep width is extrapolated from the LOGODDS model.

significant variable affecting P(x) (Table 3.8). Investigations for altitude variations are seen in Figure 3.12. They show that even at zero range, looking directly downward, CDP is approximately 0.6; that CDP is less than 0.1 beyond 0.4 nm, and that at higher altitudes the CDP is significantly lower than at lower altitudes. The curve also shows a significant bump at the medium altitudes with no real explanation. There could be a geometric cause due to viewing angle. Sweep widths are given in Table 3.9. They reduce dramatically with increases in wind speed and swell height. Time on task also accounts for a decrease in sweep width. This is probably due to the smallness of the target being searched.

Large targets were also studied in the Coast Guard program. Figure 4.2 shows data for 41' boat targets. The large lateral ranges result from aircraft being able to use the altitude advantage to see further. Lateral ranges of up to 9.6 nm were recorded.

4.4.1.2 Television Systems

There are many factors that must be considered when determining the suitability of television sensors for small object detection. The first consideration is camera types, listed as follows:

1. Black and white.
2. Low light level.
3. Active gated.

Black and white systems can be used during daylight conditions. As available light decreases, low light level systems are required. The change of light conditions is linear and continuous. Many modern low light level systems can function in the crossover range between ordinary black and white television and LLLTV, but they sacrifice extended low light capability in the very little light situation. Active gating can be integrated into both types, but it can cause image blooming problems in the very low light level situation, although the active laser also increases the amount of available light. The ability to increase the available light level will assist in target recognition after detection has been effected. A wide varity of camera types and camera tubes is available, and a manufacturer's search and evaluation

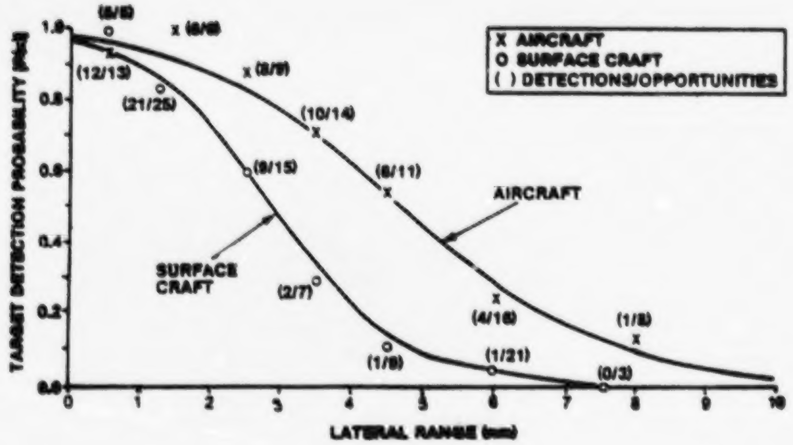


FIGURE 4.2 PREDICTED AND ACTUAL P(x) VERSUS LATERAL RANGE CURVES FOR 41-FOOT BOAT TARGETS (Edwards et al, 1981)

could be a study on its own. Table 3.11 provides information on a sample cross-section.

It is felt by the evaluators that television systems have basically been ignored because FLIR systems offer such tremendous potential for night viewing. This has resulted in very little published material on target detection using television in the open literature and has led the U.S.C.G. to decide not to extensively test LLLTV (Freezer, 1980). Studies by the U.S. Army Night Vision and Electro-Optics Laboratory reported by Freezer (1980) state that LLLTV was more severely affected by low light conditions, lack of target contrast and degraded weather. In addition, they could not be used in clear daylight conditions. To cover the full light range, a television and an LLLTV would be required.

Using the assumption that a television system would perform equally as well as the human eye, it can then be extrapolated that lateral ranges and sweep widths should be comparable. The following tests this hypothesis:

(a) Example of Probability of Detection for Television

The most important part of a television system is the lens. The optics determine the field of view. Table 4.4 gives typical fields of view for various distances and focal lengths, and Table 4.5 gives typical depths of field.

The first assumption to be made is that if a television system was used, lateral ranges would approximate visual lateral ranges. Using Figure 3.8 for a 16' lifeboat it can be seen that the lateral range can extend out to 7 nm. It is therefore safe to assume that a target could be found with a lateral range of 2.5 nm.

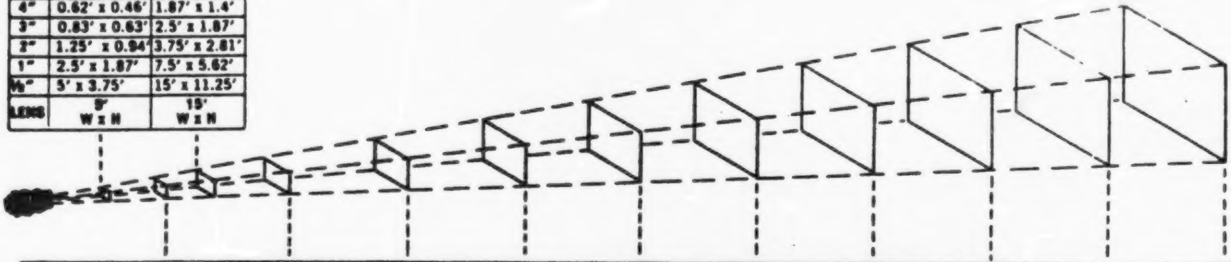
The television to be used has a zoom lens with focal lengths from 50 mm to 150 mm, or 2 in. to 6 in. To find the field of view of the lens it is necessary to find the lens-to-subject distance (Table 4.4). The assumption is made that the aircraft is flying at an altitude of 1000'. The resulting slant range is 15 003'; therefore, for each

TABLE 4.4

TYPICAL FIELD OF VIEW AT VARIOUS DISTANCES AND LENS FOCAL LENGTHS

(Electro Optic Handbook, 1974)

12"	0.21' x 0.16'	0.62' x 0.46'
8"	0.42' x 0.32'	1.25' x 0.94'
4"	0.62' x 0.46'	1.87' x 1.4'
3"	0.83' x 0.63'	2.5' x 1.87'
2"	1.25' x 0.94'	3.75' x 2.81'
1"	2.5' x 1.87'	7.5' x 5.62'
½"	5' x 3.75'	15' x 11.25'
LENS	5' W x H	15' W x H



LENS	10' W x H*	20' W x H	30' W x H	40' W x H	50' W x H	60' W x H	70' W x H	80' W x H	90' W x H	100' W x H
½"	10' x 7.5'	20' x 15'	30' x 22.5'	40' x 30'	50' x 37.5'	60' x 45'	70' x 52.5'	80' x 60'	90' x 67.5'	100' x 75'
1"	5' x 3.75'	10' x 7.5'	15' x 11.25'	20' x 15'	25' x 18.75'	30' x 22.5'	35' x 26.25'	40' x 30'	45' x 33.75'	50' x 37.5'
2"	2.5' x 1.87'	5' x 3.75'	7.5' x 5.62'	10' x 7.5'	12.5' x 9.37'	15' x 11.25'	17.5' x 13.12'	20' x 15'	22.5' x 16.87'	25' x 18.7'
3"	1.67' x 1.25'	3.33' x 2.5'	5' x 3.75'	6.67' x 5'	8.33' x 6.25'	10' x 7.5'	11.67' x 8.75'	13.33' x 10'	15' x 11.25'	16.7' x 12.5'
4"	1.25' x 0.94'	2.5' x 1.88'	3.75' x 2.81'	5' x 3.75'	6.25' x 4.69'	7.5' x 5.63'	8.75' x 6.56'	10' x 7.5'	11.25' x 8.44'	12.5' x 9.4'
8"	0.83' x 0.63'	1.67' x 1.25'	2.5' x 1.88'	3.33' x 2.5'	4.17' x 3.13'	5' x 3.75'	5.83' x 4.38'	6.67' x 5'	7.5' x 5.63'	8.3' x 6.3'
12"	0.42' x 0.32'	0.83' x 0.62'	1.25' x 0.94'	1.66 x 1.21'	2.08' x 1.56'	2.5' x 1.87'	2.92' x 2.29'	3.33' x 2.5'	3.75' x 2.81'	4.2' x 3.2'

NOTES: $$\text{*WIDTH OF FIELD (W)} = \frac{\text{LENS TO SUBJECT DISTANCE (D)}}{\text{2 X LENS FOCAL LENGTH (inches)}}$$

*WIDTH, HEIGHT AND DISTANCE MUST BE MEASURED IN THE SAME UNITS i.e. INCHES, FEET, METERS, etc. (FOCAL LENGTH IS MEASURED IN INCHES)

HEIGHT OF FIELD (H) = 0.75 X W

TABLE 4.5

TYPICAL DEPTH OF FIELD AT VARIOUS OBJECT DISTANCES AND LENS FOCAL LENGTHS

(Electro Optic Handbook, 1974)

OBJECT DISTANCE	LENS SIZE	f/1.5	f/5.6	f/16
5'	1/2"	4' to 7'	2' to 60'	1.2' to infinity
10'		6' to 35'	2.7' to infinity	1.5' to infinity
20'		8.5' to infinity	3' to infinity	1.7' to infinity
40'		11' to infinity	3.5' to infinity	1.8' to infinity
5'	1"	4.6' to 5.5'	3.8' to 7.4'	2.6' to infinity
10'		8.5' to 12.2'	6.0' to 29.5'	3.4' to infinity
25'		17.3' to 45.3'	9.4' to infinity	4.3' to infinity
50'		26.3' to 490'	11.5' to infinity	4.7' to infinity
		f/2.5	f/5.6	f/16
5'	2"	4.8' to 5.2'	4.6' to 5.4'	4.1' to 6.5'
10'		9.3' to 10.8'	8.6' to 12'	6.8' to 18.9'
25'		21' to 30.8'	17.6' to 42.9'	11.4' to inf.
50'		36.3' to 80.1'	27.2' to 307'	14.7' to inf.
		f/4	f/8	f/16
10'	3"	9.5' to 10.6'	9.1' to 11.2'	8.3' to 12.6'
20'		18.1' to 22.3'	16.5' to 25.3'	14.1' to 34.5'
50'		39.6' to 67.9'	33' to 105'	24.3' to inf.
Inf.		188' to inf.	93.8' to inf.	46.9' to inf.
		f/4.5	f/8	f/16
20'	4"	18.7' to 21.4'	17.9' to 22.7'	16.1' to 26.3'
30'		27.2' to 33.4'	25.4' to 36.6'	22.1' to 46.9'
50'		42.8' to 60'	38.5' to 71.2'	31.3' to 124'
Inf.		296' to inf.	166.7' to inf.	83.3' to inf.
20'	6"	19.4' to 20.6'	19' to 21.1'	18.1' to 22.4'
50'		46.5' to 54'	44.1' to 57.7'	39.5' to 68.2'
100'		87' to 118'	78.9' to 136'	65.2' to 214'
Inf.		667' to inf.	375' to inf.	187.5' to inf.

of the calculations, slant range approximately equals lateral range for this altitude. The field of view with the 2 mm focal length is:

$$W = \frac{15\ 000}{2 \times 2} = 3750'$$

$$H = 0.75 \times 3750 = 2813'.$$

Using Table 4.5, it can be seen that the depth of field will be infinity.

Targets on a marine background would be expected to have reasonably low reflectance values. White targets like icebergs and sea ice have a value of 0.7. Black objects like asphalt have values in the order of 0.07. Water has a value of 0.28, and red bricks about 0.5. The lighter colours have larger values than the darker colours; thus a range of 0.1 to 0.6 would seem reasonable for most targets on an ocean background (Table 4.6). The 16' lifeboat assumed in this calculation is painted orange and would probably have a reflectance of 0.56. This gives:

$$C_0 = (0.56 - 0.28)/0.28 = 1.0 .$$

If atmospheric conditions are clear, then a maximum range of detection can be found using:

$$R_m = -\ln (C_M/C_0)/\delta$$

where $C_M = 0.5$ (threshold contrast by definition),
$C_0 = 1.0$ (from above),
$\delta = 0.26$ (from Table 3.12).

Therefore:

TABLE 4.6

TYPICAL SCENE REFLECTANCE VALUES

(Remotec, 1980)

Reflected Light (Brightness in Footlamberts) =
Scene Illumination in lumens/ft^2 x Reflectance(%)

SCENE BEING TELEVISED	% REFLECTANCE
Empty Asphalt Parking Lot	7
Parkland Area, trees and grass	20
Red Brick Building	35
Unpainted Concrete Building	40
Parking Lot with Automobiles	40
Smooth Surface Aluminum Building	65
Snowy Field	75
Sea Ice	70
Icebergs	70

$$R_M = -\ln (0.5/1.0)/0.26 = 2.67 \text{ nm.}$$

From Table 2.14, an orange life raft 16' long would have a width dimension of 6'. The probability of detection can be found using the model described in 3.1.2.1(c):

$$P_1 = 1 - \exp \; [-(700/G)(a_t/A_s)t]$$

where a_t = 16' x 6',

A_s = field of view = 3750' x 2813',

G = 1 (assumed as only 1 target in area).

t = (9°/5°) x (9°/5°) x 0.3 = 0.97 sec.

(this assumes a 9 inch display).

Therefore:

$$P_1 = 1 = \exp \; [-700/1(16x16/3750x2813)0.97]$$

$$= 0.006.$$

P_2 can be obtained from Figure 4.3, using the ratio C/C_M = 0.56/0.50 = 1.12; therefore P_2 approximately equals 0.06. If the threshold contrast is taken as the noise level, then C/C_M is also the signal-to-noise ratio, and from Figure 4.3, is approximately 0.1 Using Figure 3.15, the curve for vehicle recognition (A vehicle would be of similar size as a 16' boat.), it can be seen that detection requires at least one cycle (2 picture elements) and recognition requires three cycles (6 picture elemtents) for 0.6 probability. Therefore, if N_r = 6, then from Figure 4.3, P_3 approximately equals 1.0, and if N_r = 2, P_3 = 0.02.

Therefore, the recognition probability is:

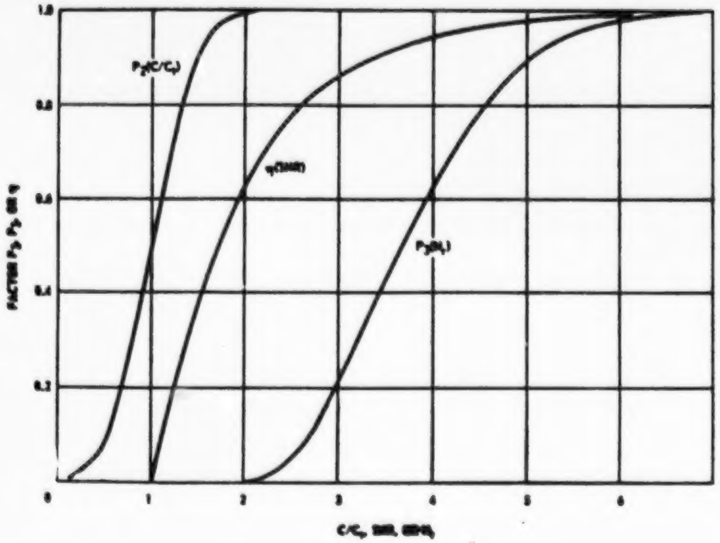


FIGURE 4.3 PROBABILITY FACTORS USED IN THE RAND CORPORATION MODEL FOR TARGET DETECTION AND RECOGNITION (Electro Optic Handbook, 1974)

$$
\begin{aligned}
P_r &= P_1 P_2 P_3 \eta \\
&= 0.006 \times 0.60 \times 0.1 \times 0.02 \\
&= 0.0000072 \text{ (for } N = 2).
\end{aligned}
$$

and the detection probability is:

$$
\begin{aligned}
P_d &= P_1 P_2 \eta \\
&= 0.00036 .
\end{aligned}
$$

From the above example, a lateral detection range of 2.5 nm was assumed. It was shown that for a lens with a 2" focal length, the field of view was 3750' x 2813' and with a 6" focal length, the field of view was 1250' x 938'. This would give ample search area to find most targets.

The second calculation assumed a 16' range lifeboat with a reflectance of 0.56. In contrast ratio calculations, a target with this contrast could be detected at at range of 2.67 nm, which is in agreement with the assumed lateral range of 2.5 nm. It must be remembered that this is for clear atmospheric conditions.

Using the probability of detection model (Bailey, 1970), it was shown that there was a very small probabability that the target could be detected and an even smaller chance of recognition. P_2, the probability that the target will have enough size and contrast to be detected was 0.60. From Figure 3.8, P(x) = 0.6 corresponds to a lateral range of 2.0 nm. It would appear that there is potential agreement between the equation for P_2 and the U.S.C.G. results for visual detection. P_1 in this equation is a measure of the observer parameters and could have some relation to the performance of the visual observers. P_3 is the recognition probability and is related to the size of the target and the range to the target, plus the angular resolution of the sensor. At a certain point, target recognition will be possible but the camera must have superior resolution.

This example shows that it is possible to detect a target at lateral ranges comparable to visual detection, but recognition is more difficult.

If the calculation is repeated for the zoom lens in the 6" focal length position, then the field of view is:

$$W = 15\,000/(2 \times 6) = 1250'.$$
$$H = 0.75 \times 1250 = 938'.$$

The range maximum will remain the same as contrast is not dependent on field of view.

P_1 will change as follows:

$$A_s = 1250 \times 938 = 1\,172\,500.$$

Therefore:

$$P_1 = 1 - \exp[-(700/1)(16x6/1250x938)0.97]$$
$$= 0.05\ .$$

P_2 remains as 0.6 and η stays as 0.1. Therefore, the detection probability becomes:

$$P_d = P_1P_2\eta$$
$$= 0.05 \times 0.6 \times 0.1 = 0.003\ ,$$

and the recognition probability becomes, for $N = 2$:

$$P_r = P_1P_2\ P_3\eta$$
$$= 0.00006\ .$$

These are instantaneous probabilities. The target will stay in the field of view for a period of time related to the forward advance of the aircraft and there will be a cumulative effect on the probabilities. If the field of view is 3750' and the aircraft is flying at, say, 150 kts/hr., then the aircraft is flying at 250'/sec. and there will be 15 instantaneous opportunities to detect the target.

(b) Example for Determining Performance of LLLTV

Using Figure 3.17, assume scene illumination of 10^{-2} Lux, which is midway between clear, no moon, and clear full moon conditions. Assume the reflectivity of the target is 20%. This gives scene illumination of 2×10^{-2}. From Table 3.11, an f/2.0 lens is reasonable for demonstration purposes. If the target to background has 30% contrast, limiting resolution is 20 line pairs/mm. If the target is the 16' boat (approximately 5 m), then a point can be found on reference B. If the lens has a focal length of 500 mm, a point can be found on reference A. From Figure 3.15, it can be seen that if $N \geq 6$, probability of detection and recognition will approach 1.0. Using $N = 6$, the lateral range will be 800 m, or approximately 0.4 nm. This shows that a P(x) vs. lateral range curve could give some meaningful results.

(c) Summary

Both these examples show that a certain level of detection and/or recognition is possible using LLLTV or ordinary television sensors. Because no tests have been conducted, there is no means to compare sweep widths with well known visual standards. Lateral ranges of television systems appear to be similar to visual lateral ranges, but model testing is only preliminary. Dependence on high quality cameras for greater lateral ranges may become a technical problems because of aircraft vibrations.

Two scenarios appear possible. In the first, a television is used to replace a visual observer and look laterally from the aircraft. From this preliminary evaluation, it would appear that the television will not outperform a human observer in daylight, but should at night. Sweep width and lateral range statistics are necessary to further evaluate this scenario. The second scenario involves the use of television in the vertical mode looking below the aircraft. Visual detection probabilities are reduced in this situation; thus, a television system could have some use. The major procedure would probably be the field of view requirements. A relatively wide angle lens would be required to cover the area where human observer capability decreases. The wide angle lens could introduce geometric distortion into the scene. As human and television performance would be the same in this scenario, television should be considered in this situation.

Active gated systems provide an auxiliary dimension to detection in that they provide a means of recognition. In the vertical scenario, they are not needed and are probably difficult to use. In the lateral scenario, consideration must be given to the range limitations of the laser with respect to the lateral range capability of the television.

Use must also be considered. If lateral range and sweep widths do not measure up to human performance, then televisions are not needed in the lateral mode during daytime. FLIRs look forward, thus LLLTV in the lateral mode could supplement night searches by providing another search dimension, especially in the shorter lateral ranges where radar sensors have diminished performance. The vertical mode for both LLLTV and ordinary television can be negated by the use of FLIRs. Certain trade-offs considering parameters beyond the scope of this study, such as aircraft/helicopter type and capability, could influence these choices.

4.4.1.3 FLIR Systems

Table 3.16 shows the limited testing done with FLIR systems. From this data, a significant lateral range decrease can be seen as soon as significant wave height becomes greater than 2'. The data shows the same sensitivity to sea state and altitude in Figure 3.18.

Not enough data have been collected to obtain suitable statistics to determine coverage factors. Because the FLIR looks forward instead of to the side, lateral range and sweep width calculations are not possible. The best method of portraying the coverage would be a moving envelope of coverage along a specific flight line. The dimension of this coverage perpendicular to the direction of flight could provide a measure similar to lateral coverage and sweep width but much detailed work would be required to develop a measure. For this reason, the U.S.C.G. uses cumulative detection probabilities as there are a number of chances of detection as a system approaches and closes in on a target.

The field of view change depends on the optics used and is comparable to the television optics. The zoom or change capability appears necessary as detection probability and recognition probability concepts could affect the mean detection range. It would appear that a more detailed and perhaps more complicated analysis of FLIR data is necessary to determine probabilities and perhaps counterparts to lateral range and sweep width.

The detection envelope would be similar to the envelope discussed for surface marine radars in Ketchen et al. (1983). Figure 4.4 gives an example. The angle coverage of the envelope would not be as extensive with FLIR systems.

4.4.1.4 Vertical Looking Scanning Systems

Vertical scanning systems look directly below the aircraft; thus, they have the potential to provide data in the area where human observers cannot see. The ground cover for a scanner can be obtained from:

$$G = 2\ H \tan\ (FOV/2)$$

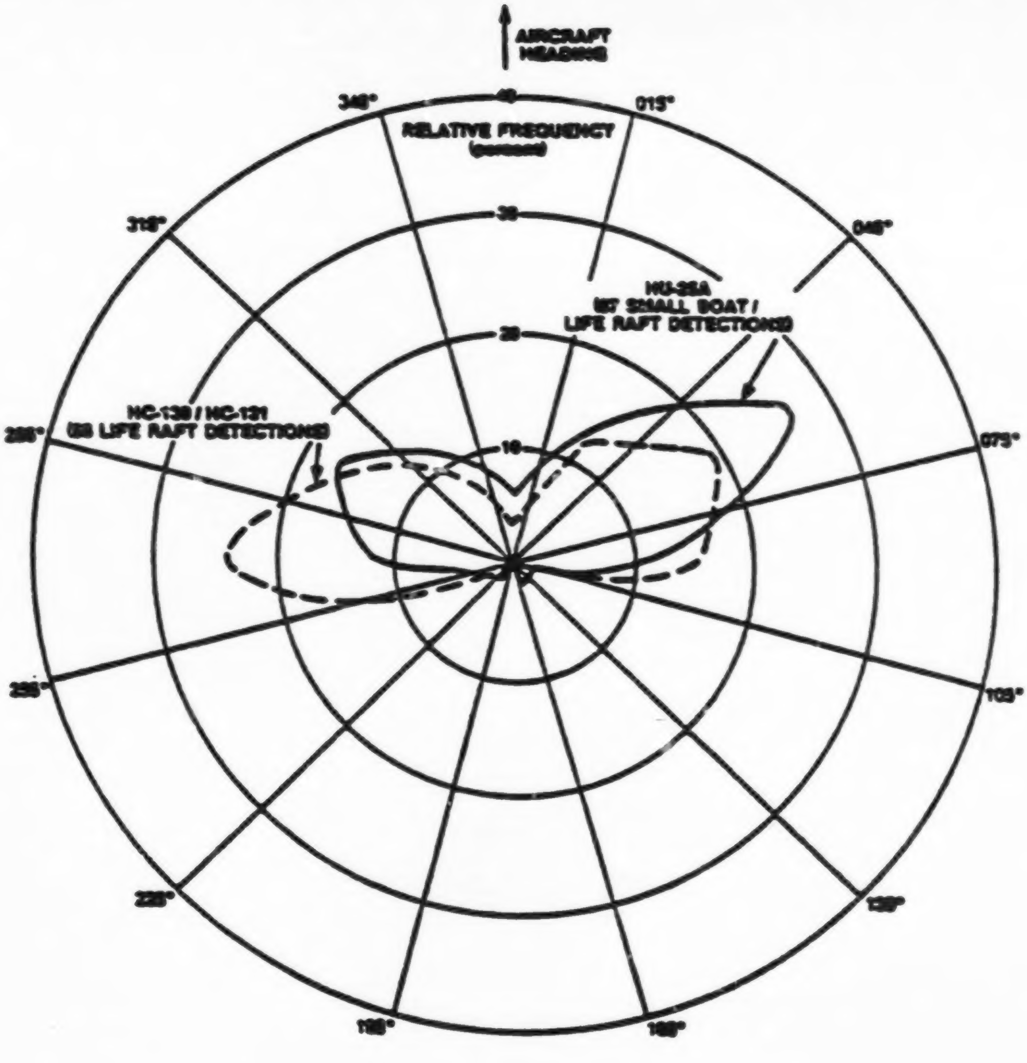


FIGURE 4.4 COMPARISON OF DETECTION ENVELOPES: HU-25A VERSUS HC-130/HC-131 (Ketchen et al, 1983)

where G = ground cover,
H = altitude,
FOV = field of view of scanner.

For an aircraft flying at 1000', with a field of view of 77° (Daedalus line scanner), the ground cover is 1591', and for a field of view of 90°, the ground cover is 2000'. Most quantitative scanners have fields of view less than 90° because of inherent distortions with wider fields of view and difficulties in keeping the scanner quantitative. This means that lateral range will be completely controlled by the aircraft altitude and sweep widths accordingly, although they should both be approximately equal. Scanners normally do not have real-time displays, although they are possible. The major problem appears to be the lateral range as scanners have temperatures and resolutions of 0.1° and spatial resolution measured in milliradians. No data are available to determine if the maximum lateral range for scanners, which is H tan (FOV/2), sufficiently overlaps the near range P(x) drop off for human observers, although intuitively, it should.

4.4.1.5 Other Sensors

Laser systems did not appear to be useful in small object detection. Lasers are somewhat range-limited and scanning lasers are only in the development stage. Lidar systems with fields of view similar to FLIR exist in the military domain. No data exist for their evaluation, but because lidar systems can penetrate water to 15 m depth and smoke screens there is some potential.

Cameras have no use in small object detection but can be used to document objects when detected.

4.4.2 Human Interface

In the case of the human observer, it has been shown that detection degrades over time. Occurrences such as eye lock and the differences between individual observers all contribute to recognition and detection differences. Tests with FLIR have shown that if the data are recorded on tape, there is an increase in detection in post flight analyses. This would indicate that the operator in the field may have suffered from video terminal fatigue. This is the same fatigue that is resulting in public health inquiries for typists and computer operators who spend all day observing video screens. This would indicate that an observer watching a video screen would have detection degradation comparable to the human observer. As an aside, this comparison should cause inquiries into the actual reality of video terminal fatigue. It may be similar to observer fatigue and not some occurrence due to the electrons emanating from the video terminal. This also indicates that if video monitors become commonplace in small object detection, then tests comparable to the human observer assessments will be required. The concept of post-flight analysis opens up new possibilities. Because the data is in an electronic format, image enhancement routines and devices, and image analysis systems and techniques can be used.

4.4.3 Environmental Effects

4.4.3.1 Visual Detection

For visual detection, the literature review showed that several environmental or environmentally-related conditions affect detection. For small targets, visibility proved not to be as important as previously thought. The U.S.C.G. recommended that sweep widths should not show an increase for visiblities that are beyond 2.5 - 3.0 times the predicted ranges for the target of interest. Increases in altitude show that there is an altitude limit where there is no variability in sweep width. For favourable environmental conditions, this range was found to be 500' - 3000'. For larger targets, higher altitudes significantly increased lateral ranges. This will have some relation to conditions of the atmosphere, but tests were not conducted during unfavourable conditions. It would be expected that the limit will decrease and environmental correlations degrade, and this limit could follow a mathematical model. Significant testing is required to identify this boundary limit of constant detection. The upper limit for large targets should also be identified, as the radar systems to be discussed in latter sections of this report have much greater range capability but sacrifice detection capability in the near range due to system characteristics. Wind speed and swell height appear to be the parameters that most significantly affect detection probabilities. The 2 m wave height appears to be the level of the first major significant change. Data were not available for higher swell heights. Wind speeds appear to have a major significant change around 25 - 30 kts. Again, higher wind speeds were not encountered in any tests. Sun angle was not shown to be the problem it was previously thought to be. The major reason is that the forward motion of the platform results in a continuous bearing change; thus, the target is not continuously up-sun. Cloud cover influences also appear to have been previously overstated.

4.4.3.2 Television

As no data exist for television; it must be compared to visual detection. Visibility conditions will affect television detection but, unlike the human eye, which is sensitive to all the visual wavelengths, selective filtration (i.e., use of haze penetrating filters) could potentially improve detection capability. Altitude increases should result in similar responses as the human observer, although attenuation due to atmospheric scattering could influence detection capabilities. Any investigation with television sensors would be assisted by atmosphere modelling studies and the use of atmospheric models such as LOWTRAN. An altitude limit will also result due to the limiting spatial resolution of the television sensor. This will be different for television and LLLTV. These limits will have to be found. Wind speed and swell height will also affect television sensing and will probably have the same magnitude as the human observer. Sun angle could be the biggest problem. Electro-optical sensors cannot look up-sun, as it burns out the camera faceplates. Many systems have automatic sun shields but these often cannot respond quickly enough.

4.4.3.3 FLIR

FLIR testing was not extensive. The major environment-related parameter that affected detection ranges and detection probabilities was sea condition (winds and wave heights). There were some sun effects, but they proved controllable. Altitude had some degrading effect, but this appeared to be mostly for system reasons. A wide enough range of test conditions was not available to determine environmental effects.

4.4.3.4 Other Sensors

No data exist for other systems. As they are mainly vertical-looking, any effects discussed in the above sections would be reduced.

4.4.4 Target Effects

4.4.4.1 Visual Detection

Visual detection showed that targets could be grouped. Three classifications emerge: PIWs (< 1 m), rafts, lifeboats and similar targets (1 - 15 m), and large vessels (> 15 m). Shape and contrast to the sea background also showed detectability influences. Targets with higher freeboards were easier to detect and bright colour targets provide the highest contrasts. There were not enough target classes in the U.S.C.G. studies to break the 1 - 15 m range into the two ranges given in Section 2.2.

4.4.4.2 Television

The size classification for visual detection will probably remain consistent. Shape will also be a major factor, but contrast will be more difficult to judge. The visual detector sees colour, while the television sees black and white. Colour television could be used for daylight searches, but there may be colour temperature problems. Black and white contrast is measured in terms of grey levels. Standard electronic sensors only see up to 16 grey levels unless they are very sophisticated.

4.4.4.3 FLIR

Target size, composition and temperature will be important with FLIR systems. Size relates to spatial resolution, while composition and temperature result in thermal resolution. Not enough information is available to properly assess these effects. FLIRs have the ability to change polarity. (Black becomes white and vice versa.) This capability should assist in improving grey level contrast, but there will still be limiting criteria.

4.4.4.4 Miscellaneous

Electro-optical sensors will have detection effects due to their fields of view. Because of this, zoom lenses will probably be necessary.

4.4.5 Sweep Widths/Probability of Detection

The U.S.C.G. experience with small object detection has led them to rewrite the manual. Most of their results are in relation to visual detection. Detection by sensors is not complete, and in the case of visual detection sensors like television and FLIR, there are not enough data to realistically rewrite the manual for these systems.

Figure 2.54a shows the generalized shape of the probability curve and sweep width for visual observation. Note that there is a slight depression at 0 lateral range. In this area, the visual observer is obscured by the aircraft and cannot see directly downward. This lowers the detection probability. This area could be covered by a FLIR or a forward looking television system or by a vertical television or vertical scanner system. This would require the evaluation of individual sweep widths and the correlation and comparison of each.

Television and LLLTV, and visual observation require a comparison. One may consistently provide better lateral range and sweep width than the other, or LLLTV can provide a night capability with enough useful lateral range and sweep width to make night searches practical. No matter which produces the best detection probabilities, there will still be a requirement to improve detection probabilities directly under the aircraft. This will require evaluation of FLIR and forward looking television, vertical television and perhaps scanning systems. The forward looking sensors must be tested to determine their detection envelope and cumulative detection probability. A detection envelope will result in a pseudo-sweep width. The vertical-looking sensors must be tested to ensure that there is enough coverage to potentially permit 100% detection probability directly under the aircraft.

The final requirement will be the determination of joint sweep widths to determine optimum value and the determination of overlapping lateral ranges and joint probabilities of detection. The use of more than one sensor system will improve detection probabilities and could result in modifications to lateral range and sweep width data. It may be possible to have maximum and minimum ranges.

The use of post flight analyses should also be encouraged. The use of image analysis and data processing systems could provide significant increase in detection probabilities.

4.4.6 Summary for Visual Detection

The evaluation of available information indicates targets greater than 15 m in length are the easiest to detect. The major problem is the establishment of an upper limit for environmental conditions. The U.S.C.G. did not have sufficient occurrence of 'bad' weather to determine if there were limiting conditions that affect detection probabilities.

The target ranges from 1 - 5 m and 5 - 15 m are combined in U.S.C.G. evaluations because they appear to have the same detection limits. This is fine for the relatively calm, good weather conditions in which the tests were carried out. It is felt by the evaluators that these data may not be valid under 'bad' weather conditions, and that these two size ranges may diverge and separate detection probabilities may result.

The last target size range, < 1 m, is already a problem in good weather. What will happen in poor weather is unknown, but indications clearly point to the requirement for active or target-aided detection. This will be discussed in a subsequent section.

4.5 All-Weather Detection

4.5.1 Systems

4.5.1.1 Side-Looking Airborne Radar

SLAR systems obey a detection law type function as shown in Figures 3.27 to 3.29. These figures show that P(x) is basically uniform to a maximum range and then quickly falls to zero beyond that range. When targets have a strong signal reflection, P(x) approaches 1.0, but if the signal reflection is weak, P(x) is low. Signal reflection depends on target composition and geometry. Shadowing of targets is the major means by which targets are missed in terms of system geometry. Environmental and target parameters also reduce detection, but in terms of system characteristics, shadowing is a major contributor to missed targets.

Figure 3.21 shows how sweep width is interpreted for SLAR. Note Area A. Part of the reason for not detecting targets within the sweep width is due to the SLAR delay space below the aircraft. This is an area where the radar signal does not record. For the Coast Guard radars, this space is set. A similar radar is mounted on a private aircraft owned by MARS Aerial Remote Sensing Limited. Their SLAR has a delay space that can be changed, allowing more variable and more flexible SLAR operations. Some types of SLARs have been optimized so there is no delay space. It can be ascertained that the larger the delay, the more chance that targets will be missed. This will in effect reduce sweep width. The U.S.C.G. studies did not account for variable and flexible delay space and hence flexible sweep width. It should also be noted that, used in conjunction with other sensors, joint P(x) and joint sweep width would result.

In U.S.C.G. studies, the AOSS system lateral range was half the lateral range for the SLAR/RIP system. The reason was the system. The AOSS aircraft range settings were not equal to the range settings of the SLAR/RIP. Therefore, one must be careful in making conclusions concerning SLAR systems. The U.S.C.G. concentrated their studies on system types. A more complete evaluation should encompass several systems, or one or two systems with greater capability. For example, the MARS system can sense swaths on each side of 25, 50 and 100 km; this doubles when employing the dual-look mode. The new U.S.C.G. APS-135 system has extended swath coverage to 200 km. This type of variability is missing from the U.S.C.G. data as published.

Polarization is another system parameter that was tested by the U.S.C.G. This was fortuitous in that they happened to have a dual antenna system. Operational SLARs today have either vertical polarization or horizontal polarization; they do not have both. Some experimental synthetic aperture radars have dual polarization capability. Figure 3.23 shows results for both polarizations. These data show that horizontal polarization appears to be better. The U.S.C.G. data called the targets they tested boats, hard targets. PIW and rubber rafts may not be hard targets unless they have attached radar reflectors.

Therefore, at this point in determining an optimal small object detection system, vertical polarization should not be ruled out.

System gain should also be considered. Radars are uncalibrated systems; thus gain settings have no quantitative meaning. When a radar is operated, the system operator adjusts the gain for the types of targets for which he is looking. Over the ocean, the operator may dial out the ocean information and optimize the system for sea ice and iceberg data collection. If the interest is in ocean structures, the gain will be adjusted to collect that type of data. The gain is adjustable at the output console; thus, when hardcopy imagery is produced, it cannot be changed. If data are recorded between the antenna and the console, then gain can be adjusted in several ways in post-flight analysis. Table 3.31 shows a small test on gain settings for the SLAR/RIP system. These tests were carried out at different altitudes. These data serve to indicate that gain settings make a difference in detection probabilities. Not enough data are available to determine conclusively the effect of gain settings. Table 3.31 shows data for small boat detection, while Table 3.33 shows the data for life rafts. The general results concerning gain are in agreement.

4.5.1.2 Forward-Looking Radar

FLAR, like FLIR, looks forward during data acquisition; therefore, cumulative detection probability was used to evaluate the systems. This permits comparison of different types of FLARs and permits a probability measure. This type of measure cannot be equated to sweep width, although if the concept of an envelope of detection is used, a pseudo-sweep width may be possible.

The U.S.C.G. tested and compared several FLARs that were in their inventory. Table 3.41 shows the comparisons made. The results of all the comparisons conclude that one system appears to be more suitable for sea state 1, and that a second system is more suitable for sea state 2. This indicates that single purpose FLARs will not meet all the requirements of small object detection and that a more complicated multi-parameter system should probably be considered.

Further tests compare U.S.C.G radars with a system from the West German Air Force. The West German system, the APS-134, consistently outperformed U.S.C.G. systems. As they carried out the test to upgrade their present capability, this comparison is fair, but it should be noted that the APS-134 was one generation more modern than the other FLARs and that there are other systems of the same generation as the APS-134 that should be tested because of their parameter variation mixes, including a system built in Canada by Litton Systems Ltd.

4.5.1.3 Synthetic Aperture Radar

Basically, these are a specialized form of SLAR; therefore, reasonable comparisons can be made because of similarities. Synthetic aperture radars have greater spatial resolution than SLAR; thus one would immediately assume they are better detection systems, but radar detection only partially depends on spatial resolution. It also depends on electronic resolution, which is related to the radar cross-section, which in turn depends on target geometry and composition. The combined resolution should be tested as the present data offers no direction. SLARs have a much greater swath width capability than synthetic aperture radars and hence may have a greater swath width. This must also be compared in terms of resolution. If the total target resolution is superior for synthetic aperture radar, its swath width may approach SLAR sweep widths in some cases. Synthetic aperture radars suffer from azimuthal smearing due to doppler shifts. This has a tendency to reduce resolution capability. This reduction may result in SLAR target data having comparable total resolution capability. This discussion shows that any small object detection test should consider both types of radars.

4.5.1.4 Passive Microwave

These systems normally look vertically, although the possibilty of forward looking systems exists. Because of the vertical look, there is a limit on width of ground coverage. These systems are the counterpart of vertical, visible, scanning systems and will have similar problems and effects. These systems have more all-weather capability than visual scanning systems. They would be used to fill in the delay space, but FLARs appear to have the capability to perform this as well as other functions. It is not expected that a passive microwave system would have a place in small object detection, based on knowledge of systems presently available.

4.5.2 Human Interface

In the case of all-weather detection systems, a human operator is a requirement. The operator, in addition to monitoring real-time data outputs, is also responsible for system timing and adjustments, and in many cases system maintenance. Thus, it is expected that the system operator will have more on his mind that just small object detection. This reduces the total concentration necessary for target searching. This, along with other problems discussed in Section 4.4.2 concerned with the visual human interface, are valid reasons for considering testing of the human operator during any detection probability experiments.

As these are all electronic systems, the data can be recorded for post-flight analysis. This was not done for U.S.C.G studies, but it is expected that detection probabilities will increase. This expectation is based on operational experiments of the evaluators involved in this study, who are experienced in providing iceberg and sea ice data to the petroleum exploration industry. Standard procedures begin by carrying out an initial image analysis in the aircraft, and following by a post-flight quality control check. This check has demonstrated that additional targets can be identified in the imagery during post-flight anlaysis. Inhouse assessment attributes this to conditions on the aircraft, operator fatigue, and interpretation conditions and situations.

4.5.3 Environmental Effects

4.5.3.1 Side-Looking Airborne Radar

Table 3.21 provides information on environmental parameters and the AOSS SLAR for the detection of small boats. For all examples, the lateral range is greater than 2 nm. The first comparison is for a variable termed as 'background'. This is really the backscatter from the ocean surface. What Edwards et al. (1980b) call a clear/light background is a calm sea with low wind speed and small wave heights. The scattered background represents a rough ocean surface with high wind speeds and high wave heights. Average conditions are given and demonstrate the backscatter conditions. The data show that detection probability decreases significantly from calm seas to what would be considered in the Grand Banks area as moderate seas. The wind speed example from the source data, Table 3.21, shows similar effects. For wind speeds greater than 10 kts., detection probabilities significantly decrease. Successful comparisons cannot be made from this table because in both cases shown the average altitude for the higher detection probability cases is higher than for the lower detection probabilities. These data can only be accepted in the general sense. The data also show that wind speed and wave height are difficult to separate and it may be necessary to consider them in the sense of a joint dependent variable.

Table 3.22 shows further data for wind speed. These data also show that detection probability decreases with increase in wind speed and subsequent increase in wave height. The data also indicate that as wind speed increased, the flying altitude decreased. This makes the comparison in this table invalid. As wind speed increases, so does the height of the waves. Higher waves result in conditions where wave height could hide a target by shadowing. Radar geometry shows that a higher altitude should have better opportunity to minimize shadow effects.

The information presented in Table 3.23 for the SLAR/RIP system is of better quality. For wind speed greater than 10 kts, detection probabilities decrease significantly. For this data set, the average altitude was constant. Wave heights were relatively constant, while wind speeds varied. Thus, the ocean surface variablity would be due to white caps caused by the wind. This condition of increasing winds without increasing sea state shows the complex variability of the wind/wave height coupling. Sometimes they appear as independent variables and other times they appear as dependent variables. The table also shows the amount of precipitation present. Precipitation on X-band, which is the frequency of the SLAR/RIP system, will degrade radar data acquisition. Thus, the wind speed effect cannot be considered conclusive.

Table 3.23 shows data for background or radar backscatter. As scatter increases, detection probability decreases. This data set also has several problems. First, the altitude change is great enough to have some significance. Second, wave height is the same in both cases, but wind speed has increased, indicating that the backscatter effect in this data set is due to whitecaps. Third, precipitation is present. These three factors make the data inconclusive in a technical sense. Although the effect is visible, the cause cannot be completely ascertained.

The precipitation data in Table 3.23 show the degradation effect caused by rain on X-band. For these data, altitudes and wave heights remain relatively constant, but wind speed increases; thus, part of the decrease in detection probability could be due to whitecaps and radar backscatter.

Table 3.23 shows the effect of increasing altitude, which was discussed above. This data set is the best presented in this table. Wind speed, wave height and backscatter are all relatively constant; therefore, altitude changes can be compared. It can be seen that as altitude increases detection probability increases. The data also indicate that there may be an upper limit to this detectability increase.

Figure 4.5 is more expressive of what is occurring. These data show increasing wind speed vs. detection probability. Altitude, as a second variable, is plotted as a family of curves. These data show that detection probability decreases with increasing wind speed and increases with increasing altitude.

Table 3.24 shows additional data for the SLAR/RIP system for a different target. These data are also inconclusive in the most technical sense, although the trends shown are consistent with other data presented. The data show that the independent variables have such a great range that all conditions cannot possibly be obtained during a

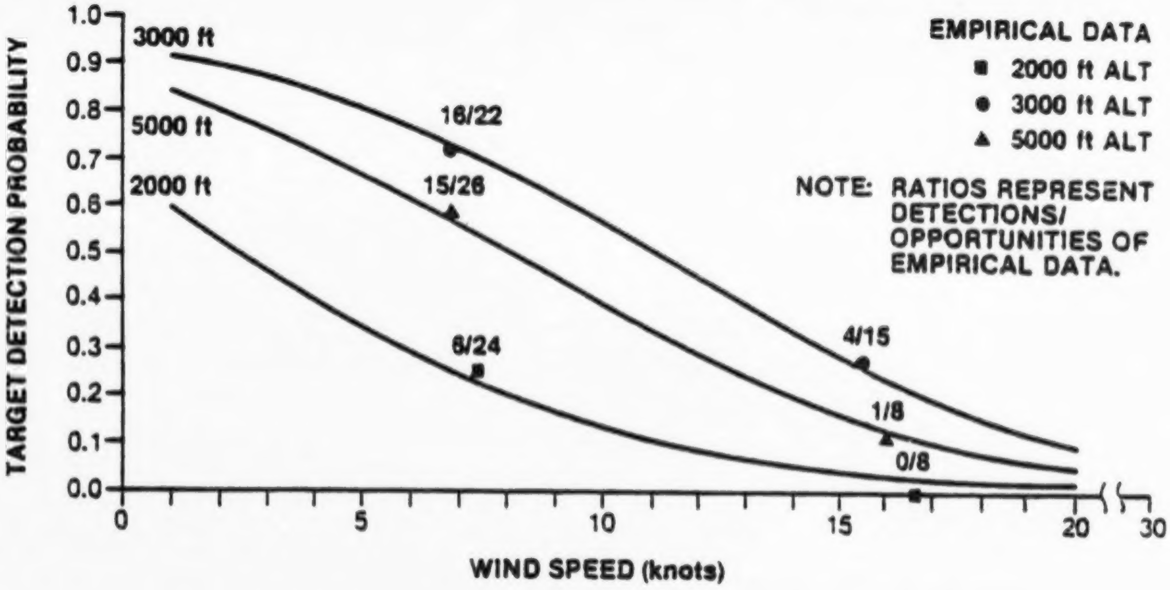


FIGURE 4.5 LOGODDS REGRESSION FITS OF TARGET DETECTION PROBABILITY VERSUS WIND SPEED AT VARIOUS ALTITUDES (SLAR/RIP SEARCHING FOR SMALL BOATS: 2 TO 18 NM LATERAL RANGES (Nash et al, 1982)

short-term experiment. This means that modelling efforts will be necessary and that follow-up comparisons with real hard data from future operational situations will be required to confirm model performance. The data also show that some of the so-called independent variables --namely, wind speed and wave height--may have some degree of dependency.

Table 3.25 shows the range of parameters studied during the U.S.C.G. studies. Although extensive, they do not cover all the situations that could occur in the Grand Banks area. Wind speed and wave height can only be considered to have reached medium or moderate values; visibilities can be as low as zero and precipitation conditions do not cover all the possibilities.

Comments should also be directed to wave direction. It appears that for theoretically-based iceberg studies, overemphasis is placed on wave conditions, when operational iceberg flights do not concern themselves with this parameter. It should be cautioned that in any follow-up study wave direction may not be an important parameter for larger targets as it is expected to be for smaller targets. This is shown in Figure 3.37, where wave orientation with respect to SLAR beam direction is shown. Table 3.35 shows the results of wave orientation effects for both radars. For the targets tested, the wave/beam orientation does not appear important for small boats, but may be for life rafts, which are smaller targets.

Table 3.28 shows more extensive data analysis based on a greater number of targets. Although there are technical discrepancies in parameter comparison, the general analysis shows that altitude increases up to an upper limit, that is of yet unidentified, increases detection probability, that visibility has no real effect on detection probability, that wind speed and wave height have some interdependence that must be defined, that antenna polarization may or may not have a real effect, that backscatter/background has not been thoroughly investigated, especially its relationship to wind speed and wave height, that the real effects of precipitation do not have enough detection opportunities to provide conclusive results, and that relative humidity appears to have no real effect. These data are for small boats. Table 3.24, shows information for life raft targets for the same AOSS SLAR. The results are basically the same. Table 3.30 gives the data for SLAR/RIP and small boats and the same general comments prevail as they do for SLAR/RIP and life rafts (Table 3.32).

In summary, wind speed and wave height appear to be the parameters that influence detection probabilities the most, followed by precipitation. These all affect the radar backscatter to varying degrees. There appears to be an overall influence on the environmental parameters by altitude. The altitude limitations must be thoroughly explored and a conclusive (although possibly varying) upper limit must be determined.

4.5.3.2 FLAR

The effects of significant wave height and FLAR are given in Table 3.37. The data do not have enough detection opportunities to give conclusive results, but they do show that wave height is important for the detection of smaller targets. Table 3.38 shows relative wave direction. There are no statistically significant differences due to wave direction. Table 3.39 shows relative wind direction. These data also show no statistical significance. Figure 3.54 shows the effect of sea state increase vs. sweep width for a 1 m^2 target. Although these data are meant to compare systems, they do show that even for the most state-of-art FLAR, sea state will have some limiting effect.

4.5.3.3 Other Radar Systems

No data exist for synthetic aperture radars and passive microwave systems. It is felt by the evaluators that the trends shown in SLAR will also occur with synthetic aperture radars. It is also felt that passive microwave sensors, because they will be limited to the vertical operating mode and have such limited coverage, will not be considered for use.

4.5.4 Target Effects

4.5.4.1 Side-Looking Airborne Radar

Figure 3.22 gives general data for small boats for P(x) vs. lateral range. These data are not related to any other parameters and show that no consistent variation exists. This means that some parameters affect detection probability. This section is concerned with target effects, mainly size and composition. U.S.C.G. data classify targets as follows: PIWs (< 1 m), boat targets (1 - 15 m), and large vessels (> 15 m). They make no size differentiation in the 1 - 15 m class.

Table 3.21 shows AOSS detection of small boats. Two target types are given in the 1 - 15 m class range. Although the environmental conditions are somewhat variable, these data show that there is a definite detection probability difference due to the composition of the target. (In this case, one target has considerable metal, while the other is solely fibreglass). Figure 3.24 shows life rafts which are also in the medium size class. Although the figure does not show the data, wind speeds were very high during detection periods, which probably adversely affected the small target detection. Figure 3.25 shows the SLAR/RIP detection of small boats. The lateral range is greater than for the AOSS system. The data show high variability due to other influences. Table 3.23 shows data for two different types of the same class of boats. There appears to be no real statistical difference. Table 3.24 shows the first real difference in targets. These data show three difference compositions of the same size class raft. It is of major interest to note that rafts with canopies and reflectors have the same detection probability as rafts without canopies or reflectors, while rafts with canopies and no reflectors have significantly reduced detection probabilities. This would indicate that radar reflectors greatly increase the detection probability and that in the case of the simple raft with no canopy or reflectors, target internal geometry has improved the target detectability. The other variables in this data set do not have the consistency to make conclusive statements concerning target detectability.

Figure 3.32 shows a comparison between the two radars for targets greater than 10 m. These data show that other than system differences there is no significant difference in the target parameters for the detection of targets of this size range.

Table 3.34 shows sweep width comparison. In general,the lateral range for SLAR/RIP is twice the lateral range for AOSS. This is system factor. These data show that for each target size class there is no statistical target difference in detection for the two systems. The differences are caused by by size and composition.

4.5.4.2 FLAR

Very little target type assessment has been carried out with FLAR. Table 3.37 shows how the presence of radar reflectors increased the detection performance and how decrease in size decreases capability. Table 3.40 also shows the increased detection capability due to the presence of radar reflectors.

4.5.4.3 Other Systems

Again, Synthetic aperture radars could be expected to produce detection probababilities similar to SLAR and passive microwave will not significantly improve detection probabilities.

4.5.5 Sweep Widths/Probability of Detection

4.5.5.1 SLAR

Figure 3.22 shows the concept of sweep width for SLAR. It can be seen that some other method is necessary to improve sweep width because of the delay space. The evaluators also feel that a different presentation concept is necessary. Sweep width should be determined based on what the sensor can see. Therefore, P(x) should only be based on what can be seen. Because targets in the delay space are not opportunities for detection, they should not be included in P(x) determinations. Thus, Figure 3.21 is not valid. This would increase the sweep width as area A would change, and because area A = area B, W increases.

It is felt that this is a more valid argument because some SLAR systems have a variable delay space.

Figures 3.27 and 3.28 show estimated P(x) vs. lateral range curves for large and medium, and small targets. These show that P(x) is not considered in the delay space. This should be translated to the calculation of W.

Figure 3.29 shows a comparison between visual and radar detection. It shows that they are searching completely different areas. No real comparisons can be made between the two unless joint probabilities and conditions exist. One works where the other does not; thus, they should be considered as joint methods that can be used together in some search scenarios.

Figure 3.30 shows the uneven search coverage for SLAR systems. This is due to overlapping coverage to fill in delay spaces. It results in some areas being covered more extensively than others.

This can also be seen in Figure 3.38. In this case, it is shown that if the delay space is ignored or covered by some other method, overlapping coverage of areas where P(x) decreases can result in cumulative POD that can increase P(x) closer to 1 again. These data are for targets greater than 10 m, where target detection is not difficult. Figure 3.39 shows data for smaller targets. In this case, to improve P(x) in regions where fall-off occurs, the overlap used results in the delay space being covered.

4.5.5.2 FLAR

Sweep widths cannot be obtained from FLAR; they are more closely related to FLIR. Cumulative detection probabilities are used to assess their performance. Instead of a sweep width, the concept of envelope coverage can be used to determine a lateral or side range capability. This could result in s pseudo-sweep width if the concept is taken further. Mean detection range can be used to establish how far detection can occur. Because state-of-art systems currently available outperform the test data, no valid conclusions can be made at present. New tests would be required to establish a range envelope. Figures 3.50 to 3.53 illustrate how, under some conditions, range can exceed 10 nm.

4.5.6 Summary

The evaluation of available information indicates that targets greater than 10 m in length are the easiest to detect. The requirement is to define the environmental limits for detection of these targets. SLAR, in particular, as well as FLAR, has a much larger range than visual sensors, but there has been no 'bad'-weather testing to determine range limitations.

For the smaller targets, detection probabilities decrease due to system controllable parameters, environmental effects and target effects. Again, bad-weather results are not available to fully determine detection probabilities.

For the smallest targets (< 1 m), range becomes limited and both visual and all-weather target detection become difficult. It appears that radar reflectors provide the best opportunity to increase detection rates.

4.6 Satellite Systems

SARSAT, in conjunction with ELTs and EPIRBs, is a proven detector and need not be evaluated. Other satellite systems in the remote sensing category have always shown promise for search and rescue detection. The limited available data from both visual and all-weather satellites indicate that satellites of this category will have little use in small object detection and that all-weather systems may be able to detect some larger vessels (> 15 m). The major problem is with resolution. The satellites do not have the spatial resolution for the required detection and probably do not have electronic or signal resolution for target identification. If targets provided assistance, such as passive or active sources, to enhance their signature, their detection by satellite might be possible, but in terms of present technology, this is not probable. Before satellites can be considered as a search and rescue tool, significant technological improvements are necessary.

4.7 Joint Probabilities

This report has looked at various methods of detection of small objects of different size classes. From the evaluation, it can readily be seen that human observation, FLIR, SLAR and FLAR are the most appropriate sensing methods and that television systems can replace and/or augment human observers. These systems can be divided into two groups: those that look laterally from the airborne platform, and those that look forward. Vertical-looking sensors can also be considered, but the field of view of television, scanners and passive microwave systems looking down is severely limited when compared to forward-looking sensors. Forward-looking sensors can more than adequately search the area that is missed or reduced by the use of lateral-looking sensors.

It can be reasonably assumed that improved search and rescue methods would utilize more than one method of sensing; therefore, the subject of joint probabilities must be considered. Joint probability of detection will demonstrate improved detection capability. To discuss joint detection, the following combinations must be considered:

(a) Lateral Sensors - Visual (human or television) and side-looking radar.

(b) Forward Sensors - FLIR or television and FLAR.

(c) Detection Overlap - Combinations of lateral and forward sensors.

Nash et al. (1982) presents some information concerning joint probabilities of detection, but very little analysis has actually be carried out.

4.7.1 Joint Probability - Lateral Sensors

Of all the sensors studied by the U.S.C.G., the human observer/scanner is the most detailed. Analysis of these studies resulted in the development of multi-variate statistical models to general lateral range curves for a wide variety of search scenarios. Table 4.7 summarizes all visual detection data.

Side-looking airborne radar was also extensively studied. Two types of radars were included. The AOSS subsystem became the operational system (subsequently replaced by the AIREYE or APS-135 system). The new radar is currently being tested, but data are not yet available from trials carried out during the spring of 1985. Because the AOSS was the operational system, only its data are considered in terms of joint probability. Table 4.8 summarizes the AOSS data base. A total of 4916 target detection opportunities for human observers, and 1216 for AOSS are considered in the following discussion. The 4916 target detection opportunities were partially from aircraft and partially from surface craft. Only the airborne data were used for joint probability discussions. The visual data base is extensive enough for the development of a visual model. The side-looking radar base is not extensive enough to cover all the variables, but it is valid for good-to-moderate weather conditions.

To carry out joint probability determination, a decision had to be made concerning the independence or correlation of the data sets. For the lateral sensors, there is only a small region of overlap of search areas. This, plus the results of individual P(x) for each method, leads to the assumption that the human observer and side-looking radars have complete independence.

If two sensors are independent, the joint or combined probability of detection for both sensors at the same lateral range, x, can be found by:

TABLE 4.7

RANGE OF ENVIRONMENTAL CONDITIONS REPRESENTED IN VISUAL DETECTION DATA BASE

(Nash et al, 1982)

SRU TYPE	TARGET TYPE	RANGE OF ENVIRONMENTAL CONDITIONS		
		VISIBILITY (nm)	WIND SPEED (knots)	SIGNIFICANT WAVE HEIGHT (ft)
Surface Craft	16-foot boats	3-20	0-25	0-5
	Life rafts	1-18	0-19	0-3
	PIWs	2-20	0-21	0-5
	41-foot boats	10-15	4-17	1-3
Aircraft	16-foot boats	3-20	0-20	0-3
	Life rafts	4-15	0-30	0-4
	PIWs	4-15	0-22	0-3
	41-foot boats	12-15	10-18	2-3

TABLE 4.8

RANGE OF PARAMETERS INVESTIGATED DURING AOSS SLAR EXPERIMENTS
(Nash et al, 1982)

TARGET TYPE	LATERAL RANGE (nm)	ALTITUDE (ft)	VISIBILITY (nm)	WIND SPEED (knots)	SIGNIFICANT WAVE HEIGHT (ft)	ANTENNA POLARIZATION	PRECIPITATION	RELATIVE HUMIDITY (%)	WAVE DIRECTION (relative to beam)
Life rafts	0-27	500-5500	1-15	3-30	0.5-3	Vertical and horizontal	Clear Fog Rain	59-100	Perpendicular Parallel
Small boats	0-27	1000-5500	1-15	3-17	0.5-4	Vertical and horizontal	Clear Rain	55-100	Perpendicular Parallel
41'-95' Coast Guard vessels	0-27	1000-5000	1-15	3-12	0.5-4	Vertical and horizontal	None	55-100	Perpendicular Parallel

$$P(x)_{combined} = 1 - [1 - P(x)_A][1 - P(x)_B] ,$$

where $P(x)_A$ = probability of detection by sensor A at lateral range x, and

$P(x)_B$ = probability of detection by sensor B at lateral range x.

If there is an indeterminant amount of correlation, it is accepted practice (Rollins, 1970, Nash et al, 1982) to average the probabilities obtained, assuming complete independence or complete correlation to estimate the combined sensor detection probability. If the assumption of complete correlation is applied, the combined sensor detection probability is the higher of the two individual probabilities.

Because the combined lateral range curves cannot be expressed as a mathematical function, the corresponding sweep widths were obtained using numerical integration (Simpson's First Rule). Sweep width is obtained from:

$$W = 2\cdot(\Delta X/3)\ (P_1 + 4P_2 + 2P_3 + 4P_4 + \dots + P_n) ,$$

where P_n denotes the n^{th} equally spaced probability ordinate in the lateral range curve, and Δx denotes the ordinate spacing in nautical miles. The multiplier 2 is used in order that only one side of the lateral range curve needs to be multiplied (the curve must be symmetric).

Using this methodology, Nash et al (1982) generated Figures 4.6 - 4.10 for two sets of weather conditions and three target types. These data show that search altitude and target type are the critical parameters for SLAR, while all parameters affect visual detection. These curves show that visual search effectively augments SLAR coverage by filling in the blind zone and immediately adjacent areas.

Table 4.9 gives the sweep widths calculated from the combined data. These values are 5 - 8% higher than AOSS SLAR values discussed earlier; therefore, they reflect added area coverage.

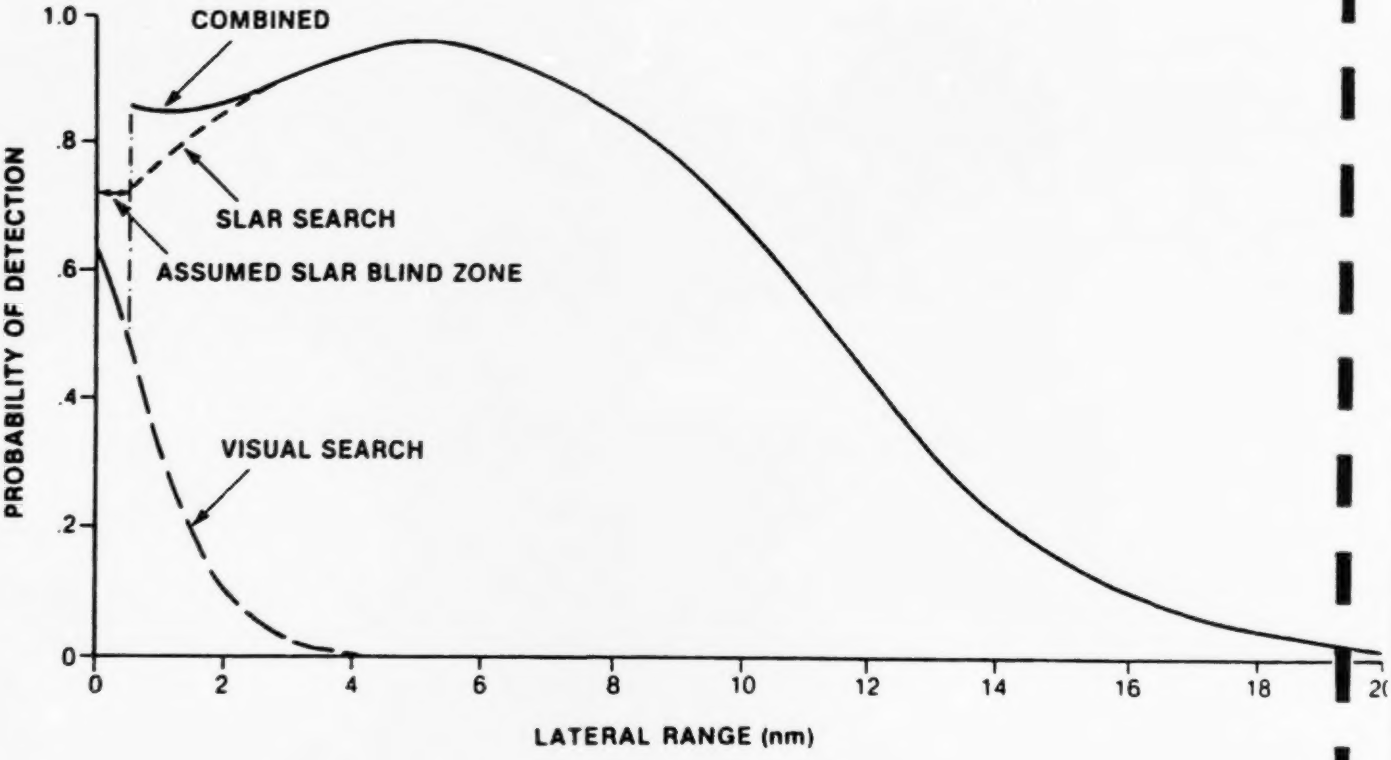


FIGURE 4.6 AOSS SLAR/VISUAL SEARCH PERFORMANCE IN FAIR CONDITIONS; FULLY EQUIPPED 16- TO 21-FOOT FIBERGLASS BOAT TARGET

(Nash et al, 1983)

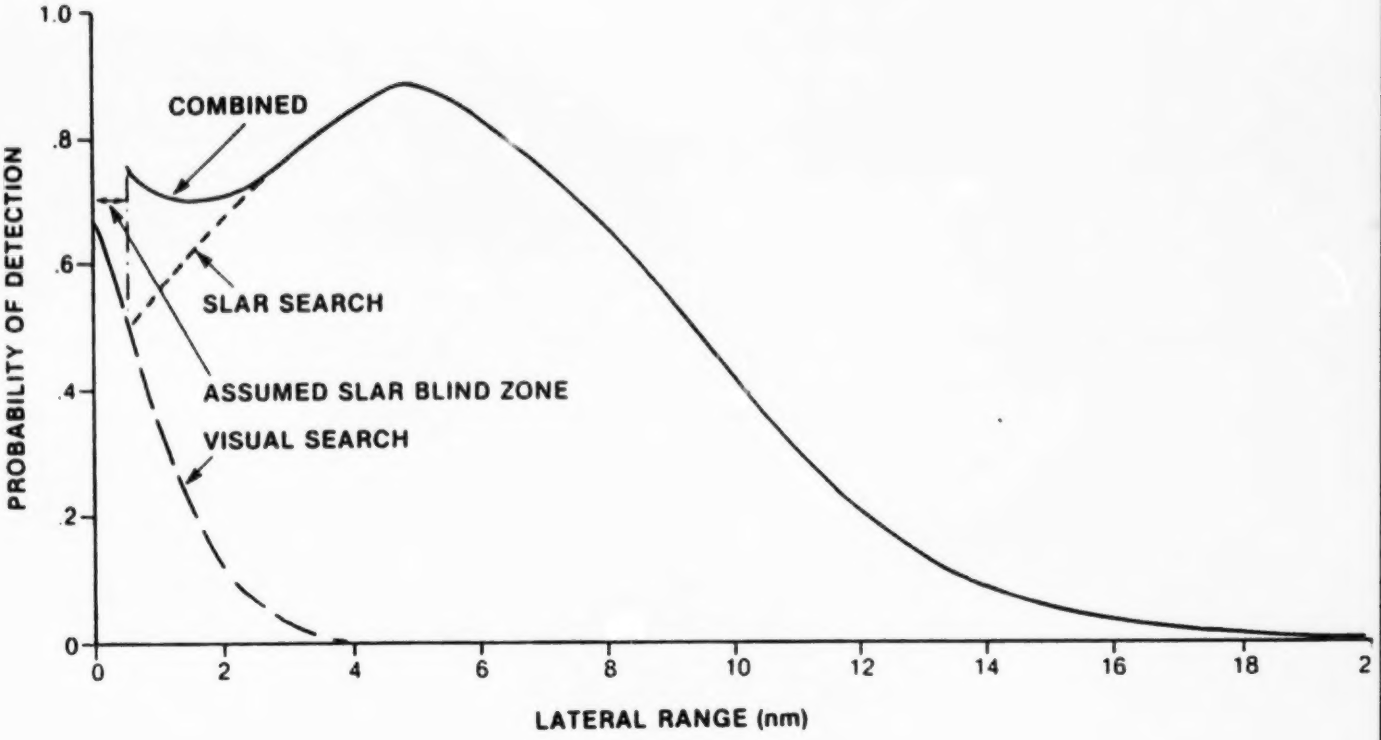


FIGURE 4.7 AOSS SLAR/VISUAL SEARCH PERFORMANCE IN GOOD CONDITIONS; BLUE, 16-FOOT FIBERGLASS BOAT TARGET WITHOUT REFLECTIVE EQUIPMENT (Nash et al, 1983)

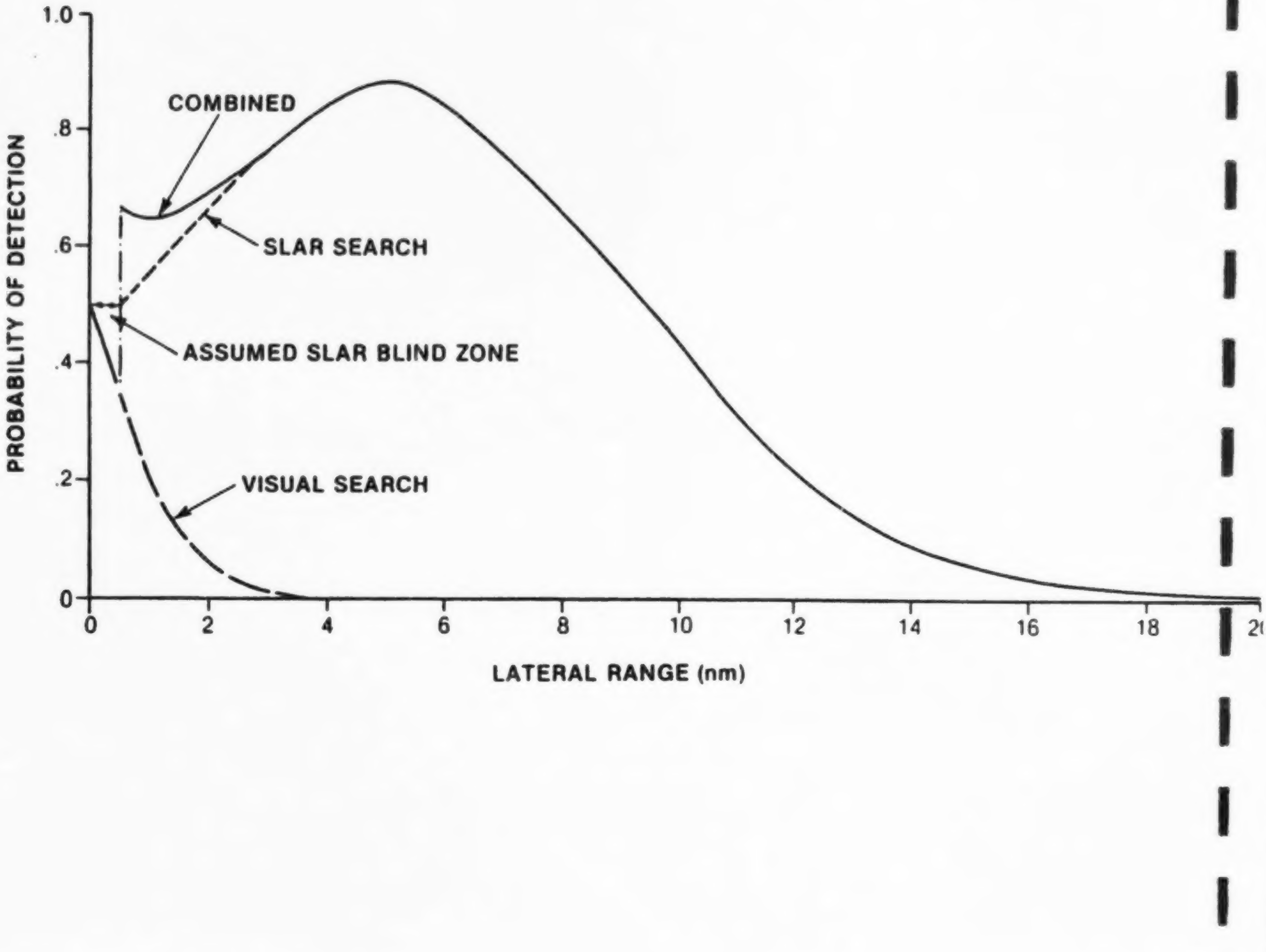


FIGURE 4.8 AOSS SLAR/VISUAL SEARCH PERFORMANCE IN FAIR CONDITIONS; BLUE, 16-FOOT FIBERGLASS BOAT TARGET WITHOUT REFLECTIVE EQUIPMENT (Nash et al, 1983)

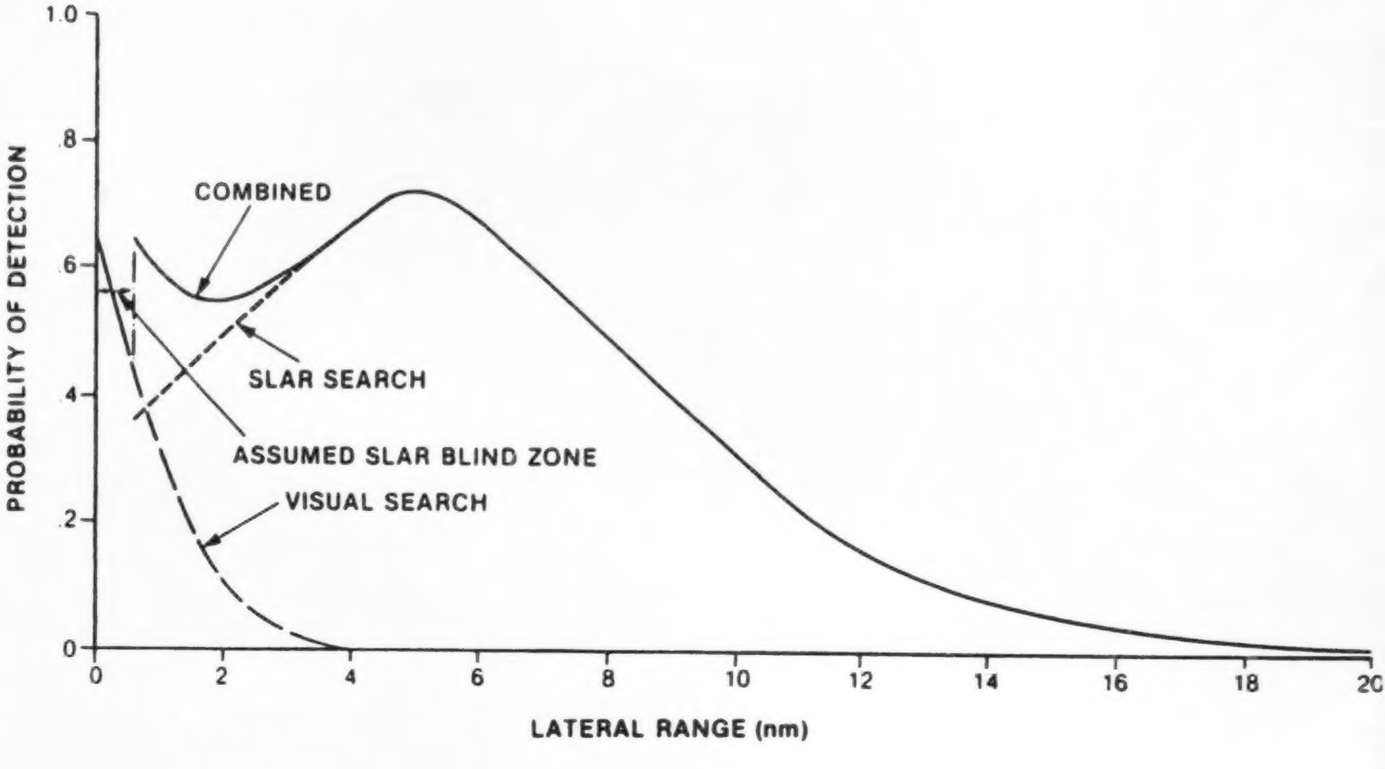


FIGURE 4.9 AOSS SLAR/VISUAL SEARCH PERFORMANCE IN GOOD CONDITIONS; BLACK, 7-MAN LIFE RAFT TARGET WITHOUT RADAR REFLECTOR

(Nash et al, 1983)

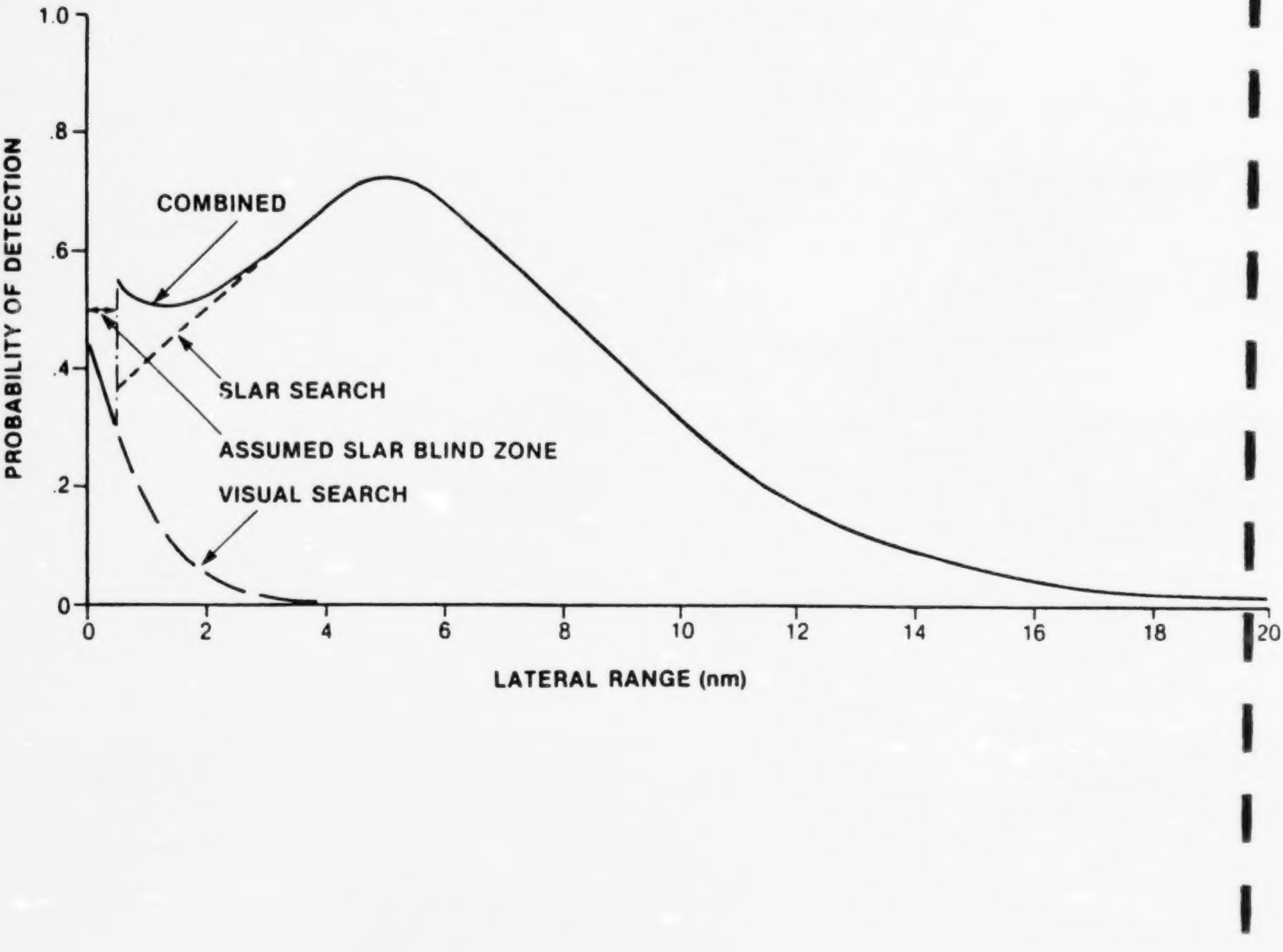


FIGURE 4.10 AOSS SLAR/VISUAL SEARCH PERFORMANCE IN FAIR CONDITIONS; BLACK, 7-MAN LIFE RAFT TARGET WITHOUT RADAR REFLECTOR

(Nash et al, 1983)

TABLE 4.9

SWEEP WIDTHS (in nautical miles) FOR COMBINED AOSS SLAR/VISUAL SEARCHES

(Nash et al, 1983)

TARGET TYPE	ENVIRONMENTAL CONDITIONS*	
	GOOD	FAIR
High-contrast (e.g., white), 16- to 21-foot fiberglass or aluminum boat with engine and/or other metal equipment	22.0	21.8
Medium-contrast (e.g., blue), 16-foot fiberglass boat without engine or other metal equipment	17.1	16.8
Black life raft without metal equipment or canopy	13.7	13.3

*"Good" and "Fair" environmental conditions were defined in the preceding text.

The use of television sensors must be examined. First, SLAR is an all-weather system which also means that it can fly at night. Therefore, if television systems can offer comparable lateral range to human observers, then LLLTV can be used in conjunction with SLAR at night. Second, if it can be shown that television systems can improve upon human observer lateral range, then the human observer can be replaced by television systems and the observer can be used to monitor video screens in more comfortable operating conditions.

4.7.2 Joint Probability - Forward-Looking Sensors

No studies have been carried out comparing FLIR performance with FLAR. If lateral sensors are considered to be analogous, similar results should occur. The FLIR is analogous to the human observer and should have a high P(x) close the aircraft. FLAR is analogous to SLAR and should have good lateral range coverage. Because there is no blind spot below the aircraft, there will be overlapping coverage, but technical considerations concerned with sea clutter in the near range of the FLAR effectively create a blind zone. It therefore appears that the FLIR/FLAR system is analogous to the visual/SLAR system and it can be expected that lateral range and sweep widths will increase. Because of the overlapping coverage for some parts of these sensor ranges, the problem of partially correlated systems may have to be dealt with.

Television sytems could be used in place of FLIRs. If so, similar determinations for lateral range and sweep width will be necessary to compare performance.

4.7.3 Detection Envelope

It is conceivable that combinations of lateral and forward looking sensors will be used together, or that a complete sensor suite may be possible. It will be necessary to develop a method whereby lateral range and sweep performance can be statistically compared. Nash et al (1982) developed a method for comparing ship search radar and human observer detection. This method involves the calculation of instantaneous detection probabilities vs. actual range using the radar range equation. From the instantaneous detection probabilities, lateral range curves were generated using:

$$y_u = \sqrt{R_m^2 - x^2}$$

$$k_p = \sum_{y=o}^{y_u} P(\sqrt{y^2 + x^2})\ \Delta y$$

$$P(x) = 1 - \exp(-ck_p)$$

where $P(x)$ = probability of detecting a target that closes to lateral range along a path parallel to the search vessel's track,

c = a multiplicative factor used to bring theoretical predictions as close as possible to experienced results,

y = range from target to closest point of approach along a line parallel to search vessel track,

R_m = selected maximum sensor range,

$P(\sqrt{y^2 + x^2})$ = instantaneous probabilities of detection at range $r = \sqrt{y^2 + x^2}$.

This can be depicted graphically as shown in Figure 4.11. The integration if repeated for a number of lateral ranges from 0 to maximum sensor range results in P(x) vs. lateral range curves for each data group.

Another problem concerned with the comparison of forward and lateral sensors is the relationship between cumulative detection probability curves and lateral range curves. The CDP curves provide a detailed picture of how range, sensor type, target type and environmental parameters affect P(x). They are also used to determine the operator factor which is required for lateral range calculations.

The operator factor is called Po and is the probability that an operator, not knowing a target location, will see a recognizable blip on the display (Osmer et al, 1982). This can be expressed mathemat-

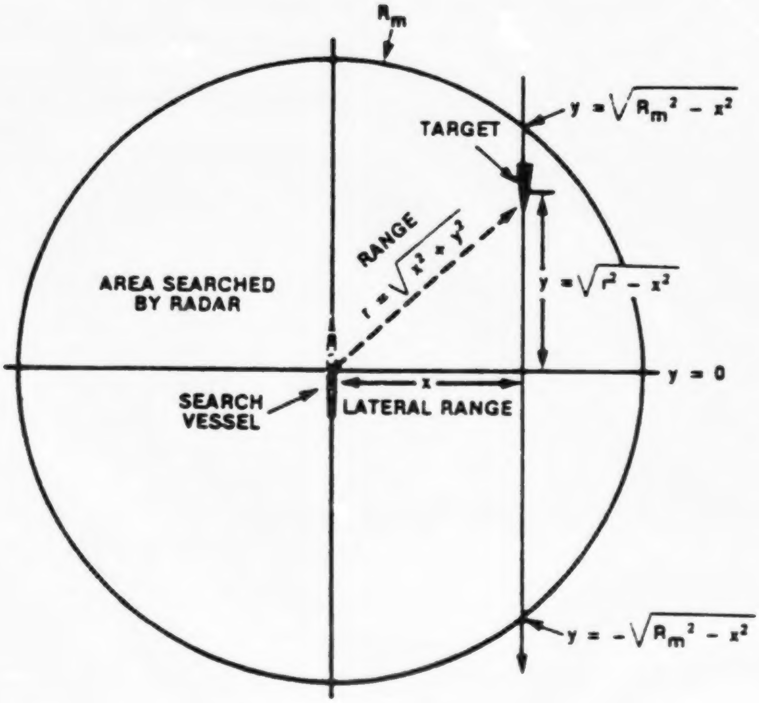

R_m
$y = \sqrt{R_m^2 - x^2}$
TARGET
RANGE
$r = \sqrt{x^2 + y^2}$
$y = \sqrt{r^2 - x^2}$
AREA SEARCHED BY RADAR
$y = 0$
x
SEARCH VESSEL
LATERAL RANGE
$y = -\sqrt{R_m^2 - x^2}$

FIGURE 4.11 SEARCHER-TARGET INTERACTION AT LATERAL RANGE x
(Nash et al, 1982)

ically. Lateral range curves are then generated using the methods outlined in the U.S.C.G. reports with the operator factor used to modify P(x). The method given by Osmer et al (1982) is for search radars on ships, but similar methodology can be developed for FLIR and FLAR.

Lateral range and CDP curves intersect the P(x) axis at a common point when lateral range is zero. This can be seen in Figure 4.12. Once lateral range is determined, sweep width can be calculated.

This method should be extrapolated to FLIR and FLAR to determine what has been called pseudo-sweep widths in this evaluation. Once this has been done, the instantaneous detection envelope can be constructed around a platform and the joint P(x) can be determined.

4.8 Summary

This chapter has been devoted to the evaluation of data presented in Chapters 2 and 3 to determine the most suitable sensor systems for small object detection. Probability data taken from U.S.C.G. reports has been examined. In general terms, small object detection for targets less than 1 m will, at the least, be difficult, for the two ranges from 1 - 15 m, detection appears possible, limited by existing environmental and target conditions. For targets greater than 15 m, detection is highly probable. The U.S.C.G data do not provide upper or worst weather limits on detection probabilities and until these are known, conclusive statements cannot be made concerning detection probabilities, and operational numbers such as sweep width cannot be formalized.

From the evaluation it can be seen that joint use of sensor systems increases lateral range and sweep width, but not enough data are available to make conclusive statements.

The evaluation shows that more work is required before operational numbers are available. The environmental limits must be identified and the joint probabilities developed. The U.S.C.G. data base is sparse to extensive, depending on sensors evaluated. This data base should be further developed until it is complete in all aspects. This requires further experimentation with sensors. It must also be noted

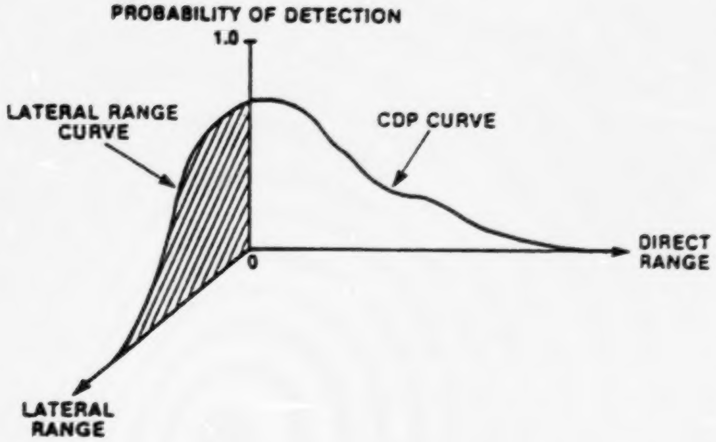

PROBABILITY OF DETECTION
1.0
LATERAL RANGE CURVE
CDP CURVE
0
DIRECT RANGE
LATERAL RANGE

FIGURE 4.12 RELATIONSHIP BETWEEN CDP AND LATERAL RANGE CURVES
(Nash et al, 1982)

that U.S.C.G. tests involved systems that they were using or expecting to use. Therefore, further tests should involve systems that might be used in Canada. The evaluation shows that the most promising sensors are television, FLIR, side-looking radar and FLAR. Scanning systems and passive microwave are "exotic" sensors at present and should not be tested unless the other sensors do not perform as required.

CHAPTER 5

PRELIMINARY EXPERIMENTAL PLAN

5.1 Proposed Test Period and Area

The data presented in this evaluation show that January to March will provide the extreme environmental conditions required to establish the environmental limits required for detection probabilities.

Two test areas are required. One test area should be nearshore and it is recommended that the test be carried out in a large ice-free bay such as Placentia Bay, Newfoundland. The second test area should be the open ocean, preferrably the Hibernia area. Environmental conditions in these two areas meet the requirements.

5.2 Targets

A full range of targets as outline in Section 2.2 is required. There must be enough targets present to maximize detection opportunities with available flying time. Target location is not as critical with airborne platforms as with surface platforms, but a joint strategy should be developed between the two groups to optimize target location for both types of tasks, airborne and surface. Targets should be moored so the approximate loaction is known. A means of accurately positioning some targets is necessary, while others can be located relative to fixed positions. Targets should be as realistic as possible. Therefore, PIWs should give off heat at rates similar to those of a human body, and life rafts and vessels should be of types commonly in use. Specially-designed capsuled life rafts should be tested, but because these are not in widespread use, they should not dominate the target listings. An attempt should be made to carry out tests near shipping lanes or fishing areas so that the number of larger boats can be increased at no cost to the experiment.

5.3 Schedule

A tentative schedule can be developed. Approximately four months are required for logistics, installation and planning. Two weeks are needed for mobilization to carry out experiments in the first test area. Two weeks are required to collect data. This allows enough time to experience the full range of potential environmental conditions. One week is required to move from one area to the other, particuarly for the movement of vessels and gathering and laying of moorings. Two weeks are required for data acquisition at the second site to ensure the potential full range of environmental conditions. A week will be required for demobilization, and possibly a second week for the demobilization of vessels. Four months will be required for the basic data analysis and if the data set achieves all expectations, a further two weeks will be required for advance statistical analysis and preliminary modelling.

Therefore, to commence data acquisition in February, it will be necessary to begin in October with planning, logistics and installations.

5.4 Test Vehicles

A number of airborne test vehicles are available in Canada and the U.S.C.G. has means to provide aircraft support if approached early enough. Some platforms are operated by the government and others are in the hands of private industry.

The Atmospheric Environment Service, Ice Central operates out of Gander during the proposed test period, with a side-looking airborne radar onboard their aircraft. Given a detailed data acquisition plan, they could support these tests as long as there is is no interference with the standard operations.

The U.S.C.G. International Ice Patrol normally begins operations out of Gander during March. They have aircraft commitments based on a flying year and have some flexibility to provide an aircraft in February, especially when it is in the interest of their own activities.

DND could potentially provide aircraft support, but must be approached early. Dependent upon which aircraft they make available, they could provide FLIRs and FLARs.

MARS Aerial Remote Sensing Limited has operated a private ice/iceberg patrol on behalf of east coast petroleum operators in both the 1984 and 1985 ice seasons. This aircraft contains a side-looking airborne radar and has space available for FLIRs, FLARs and television systems.

Intera operates a synthetic aperture radar, but there is no room for other sensors onboard their aircraft. The swath width of the synthetic aperture radar cannot meet the capability standards of the SLAR, but as this type of radar has not yet been tested, it should receive consideration.

CCRS operates a synthetic aperture radar as well; it has much more scientific capability because different frequencies and polarizations are available. If a decision is made to test synthetic aperture radars, this would be the best choice because of its capabilities.

From the above, it is apparent that side-looking radars will be available; it is the other sensors that are not. These will have to be obtained in some manner. Because the test period is relatively short, it may be possible to have manufacturers demonstrate their systems. For example, Litton Systems have indicated that their FLAR could be made available, and the evaluators have had previous experience with short-term rentals/loans for FLIR and television sensors.

If it is felt that further visual detection tests should be carried out, experienced search and rescue observers should be obtained from either DND or the Coast Guard.

5.5 Other Comments

This program will be rather large and complex in terms of potential participants. As NORDCO has been responsible for surface detection and F.G. Bercha and Associates responsible for airborne detection, their contact lists will be different, although there may be some overlap in agencies. Expected participants would be: the Canadian Coast Guard, U.S.C.G., DND, AES, NORDCO, and F.G. Bercha and Associates. Additional support may be possible from the oil industry, Bedford Institute of Oceanography, and the North West Atlantic Fisheries Centre. Funding sources are not the mandate of the evaluators, but NOGAP and OERD, as well as departmental sources are potential sources. From the commercial sector, unless manufacturers cooperate, added funds will be required. To successfully bring these sources together will require joint planning by the participants and scientific authorities of both evaluation studies.

This outline is only the preliminary basic requirement. It is necessary to begin detail planning as soon as possible in order to develop a detailed study specification.

5.6 Cost Estimate

Only a first order of cost is introduced. No attempt has been made to separate hard costs from support-in-kind, although this will be identified where possible. The following are anticipated costs:

(a)	Ground Truthing: Targets, buoys, vessels on site, etc.	$250 000 (partially support-in-kind).
(b)	Preliminary Planning, Logistics, etc.	$20,000 .
(c)	Airborne Platforms	$250 000 (plus support-in-kind from AES and IIP)
(d)	Additional Sensors and Installations	$400 000 (unless loans can be arranged).
(e)	Field Operation Costs	$ 50 000.
(f)	Data Analysis	$ 50 000.

Therefore, the approximate first order costs for an airborne program would be $1 000 000. Some of these costs would be shared with a surface measurement program.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on this evaluation, several conclusions can be made concerning the detection of small objects on an ocean background. These conclusions relate to various aspects of the total concept.

6.1.1 Environment-Related

(a) Previous studies have not been carried out in 'bad' conditions such as would be encountered off Canada's east coast.

(b) The interdependence/correlation of wind speed and significant wave height have not been resolved.

(c) The degrading effects of visibility and precipitation have been established.

6.1.2 Target-Related

(a) Targets < 1 m have been established as a valid target class.

(b) Targets > 15 m have been established as a valid target class.

(c) No division of the range 1 - 15 m has been established, although targets themselves tend to be less than 5 m or greater than 10 m, with very few being between 5 and 10 m.

(d) No valid conclusions have been made concerning target composition.

(e) No characteristic signatures have been established for targets (i.e. backscatter coefficients or characteristic returns).

6.1.3 System-Related

(a) The altitude limits or envelopes have not been precisely delineated.

(b) No polarization or filtration effects have been defined to determine if target enhancement can be achieved.

(c) No search speed limits have been defined except for vessel search by human observers.

(d) No conclusive results exist for observer performance except for human observation.

6.1.4 Sensors

(a) The human observer has been statistically validated as a sensor system.

(b) Side-looking airborne radar has not been validated statistically because of the lack of detection opportunities under bad weather conditions.

(c) FLIR and FLAR have not been statistically validated.

(d) Television systems have not been tested as a replacement for the human observer or for night flight extension.

(e) Other sensor systems do not appear to have potential for small object detection as they are presented configured. This rules out scanners, lasers/lidar and passive microwave.

(f) ELTs and EPIRBs are already state-of-art systems in use based on sound. They were not evaluated; neither were other sound-based systems such as geophones and voice receivers, as no literature existed and these systems were not in an existing form.

(g) No tests have been carried out for multi-sensor suites except for joint side-looking radar/visual joint detection probabilities.

6.1.5 Search and Rescue Parameters

(a) P(x) vs. lateral range and W have been established for human observation.

(b) P(x) vs. lateral range and W have not been validated statistically for other sensor systems.

(c) The relationship between CDP and lateral range, and subsequent sweep width has not been established for forward-looking sensors.

(d) Joint probability relationships have not been established for lateral sensors, forward sensors or mixed suites. This has almost been completed for SLAR/visual, except for the question of determining sweep width raised by the evaluators.

(e) The sweep width definition for sensors with delay space or detection gaps must be reconsidered.

6.1.6 Field Programs

(a) There is a need for a detailed development of a field plan to test and validate sensors under uniquely Canadian conditions.

(b) There is a requirement to establish search and rescue guidelines in terms of P(x) and W for any of the recommended electronic sensors.

6.2 Recommendations

The following recommendations are derived from the evaluation and conclusions. These are identified as practical and theoretical.

6.2.1 Environment-Related

(a) A field program should be carried out under 'bad' weather conditions relative to Canadian requirements (practical).

(b) The interdependence/correlation of wind speed and significant wave height and their relation to small object detection should be determined (theoretical).

6.2.2 Target-Related

(a) The size range 1 - 15 m should be subdivided to realistically reflect standard targets (practical).

(b) Characteristic signatures should be defined for each target/sensor interaction group (theoretical).

6.2.3 System-Related

(a) Altitude limits should be defined (practical).

(b) Polarization/filtration effects should be tested (theoretical).

(c) Search speed limits should be defined (practical).

(d) Human observer vs. system observer performance should be evaluated (theoretical).

6.2.4 Sensors

(a) Side-looking airborne radar should be evaluated statistically (practical).

(b) FLIR and FLAR should be validated statistically (practical).

(c) Television systems should be tested for human observer replacement (practical).

(d) Synthetic aperture radar should be tested and compared with SLAR results (practical).

(e) Multi-sensor suites operating from the same platform simultaneously should be tested (practical).

6.2.5 Search and Rescue Parameters

(a) P(x) vs. lateral range and W should be validated for all suitable sensors (practical).

(b) The relationship between CDP and lateral range should be established (practical).

(c) Joint probability relationships should be established for all combinations of systems (practical).

(d) The concept of sweep width should be re-examined in terms of sensors with zones that are unable to detect targets and their effect on the ultimate W number (theoretical).

6.2.6 Field Programs

(a) It is recommended that a field program be planned to include as many of the above recommendations as possible.

(b) It is recommended that search and rescue guidelines be established for Canada.

REFERENCES

Anderson, A. (1978) "Remote Sensing in Sea Search and Rescue", Remote Sensing of Environment, 7, 269-271.

Aviation Week and Space Technology (1983), November 28.

Author Unknown (1983) "Field Evaluation of Model 1000A FLIR" U.S.C.G. 731010.2.

Bailey, H.H. (1970) "Target Detection Through Visual Recognition: A Quantitative Model" Rand Corporation, Santa Monica, Ca.

Blackwell, N.J.; S.R. Osmer; R.P. Simmons; M.L. Everson; and J.R. Watson (1982) "Preliminary Study On Scanning Techniques Used By U.S. Guard Lookouts During Search and Rescue Missions" Report No. CG-D-50-82, 66 pages.

Canadian Climate Centre (1984) Documents Taken from Climate Centre Data Base.

de Villiers, J.N. (1973) "Airborne Detection and Mapping of Oil Spills, Grand Bahamas, February 1973", CCRS 100-5299, 14pp.

Edwards, Jr., N.C.; S.R. Osmer, T.J. Mazour and D.B. Bouthilette (1978) "Analyses of Visual Detection Performance (Fall 1978 Experiment)" Report No. CG-D-03-79, 124 pages.

Edwards, Jr., N.C., S.R. Osmer, T.J. Mazour and G.L. Hover (1980a) "Analysis of Visual Detection Performance for 16 Foot Boat and Life Raft Targets" Report No. CG-D-24-80.

Edwards, Jr., N.C.; S.R. Osmer, T.J. Mazour and R.D. Bermont (1980b) "Evaluation of National SAR Manual Probability of Detection Curves" Report No. CG-D-41-80.

Edwards, Jr., N.C.; S.R. Osmer, T.J. Mazour and G.L. Hover (1980c) "Analysis of Side-Looking Airborne Radar Performance In The Detection of Search and Rescue Targets" Report No. CG-D-31-80.

Edwards, Jr., N.C.; S.R. Osmer, T.J. Mazour and G.L. Hover (1981) "Factors Affecting Coast Guard SAR Unit Visual Detection Performance, Report No. CG-D-09-82.

Edgerton, A.T., J.J. Bommanto, R.S. Schwantje and D.C. Meeks (1975) "Development of a Prototype Oil Surveillance System, Final Report" DOT-USCG, Washington D.C., Aeroject Electrosystems Company, DOT #1812FR-1.

Electro-Optics Handbook (1974) RCA Technical Services EOH-11, 255 pages.

REFERENCES - Cont'd.

F.G. Bercha and Associates Ltd. (FGBAL) (1984) "An Investigation of Remote Sensing Equipment for Chronic Oil Discharge" Environment Canada Report.

Freezer, D.R. (1980) "Design Considerations for U.S. Coast Guard Search and Rescue Surveillance Forward Looking Infrared (FLIR) System" SPIE Vol. 253 Modern Utilization of Infrared Technology VI, P. 247-253.

Grover, C.G., and W.L. King (1977) "Night Identification Camera" Proc. from Soc. of Photo Optical Instrumentation Engineers Vol. 108 Optics in Security and Law Enforcement p. 39-44, Naval Surface Weapons Centre, Silver Spring, Maryland CCKS 102-9000.

Gower, J.F.R. (1982) "General Overview of the Nature and Use of Satellite Remote Sensing Data for Fisheries Application" NAFO Sci. Coun. Studies 4, p. 7-19.

Hover, G.L.; T.J. Mazour, S.R. Osmer and L. Nash (1982) "Evaluation of Forward Looking Infrared (FLIR) As A Coast Guard SAR Sensor" IEE 82 CH1827-5, p. 491-495.

Hotzel, J.S. and Miller, J.D. "Icebergs: Their Physical Dimensions and the Presentation and Application of Measured Data", Annals of Glaciology, Vol. 4, 1983, pp. 116-123.

Ketchen, H.G., L. Nash, and G.L. Hover (1983) "Analysis of U.S. Coast Guard HU-25A Visual and Radar Detection Performance" Report No. CG-D-20-83.

Ketchen, H.G.; J. St. Martin, G.L. Hover and T.J. Mazour (1984) "Evaluation of U.S. Coast Guard Forward-Looking Airborne Radars" Report No. CG-D-17-84.

Koopman, B.O. (1946) "Searching and Screening" U.S. Navy OEG Report No. 56.

Lapp, P.A. (1975) "An Investigation of Systems for the Surveillance and Monitoring of Oil Spills at Beaufort" CCRS 101598321015986, 72 pp.

Lozniski, S., and R. Corriveau (1984) "Implementation of a FLIR Performance Model in TI-59 and HP-41 Hand Held Calculators" DREV Report 3633A-053.

Marine Environmental Data Service (1984). Documents taken from Data Service Data Base.

Markham, W.E. (1980) "Ice Atlas, Eastern Canadian Seaboard", Environment Canada.

REFERENCES - Cont'd.

McDonnell, M.J. and A.J. Lewis (1978) "Ship Detection from Landsat Imagery" Photogrammatic Engineering and Remote Sensing Vol. 44, No. 3, pp. 297-301.

Nash, L.; G.L. Hover and R.E. Burns (1982) "Additional Analyses of Probability of Detection (POD) in Search and Rescue (SAR) Project Data Report No. CG-D-55-82.

Newfoundland Petroleum Directorate (1984) Internal Documentation

Ochiai, H., and Tsuchiya K. (1981) "Application of Multispectral Data To The Detection of Sea Surface Phenomena" (1981) Adv. Space Res. Vol. 1, pp. 165-176.

Osmer, S.R.; N.C. Edwards Jr., G.L. Hover, and T.J. Mazour (1981a) "Evaluation of Two AN/APS-94 Side-Looking Airborne Radar Systems In The Detection of Search and Rescue Targets" Report No. CG-D-64-81.

Osmer, S.R., N.C. Edwards, Jr., G.L. Hover and T.J. Mazour (1981b) "Preliminary Assessment of Coast Guard Surface Vessel Radar Detection Performance" Report No. CG-D-63-81.

Osmer, S.R., L. Nash, G.L. Hover and T.J. Mazour (1982) "Coast Guard Surface Vessel Radar Detection Performance" Report No. CG-D-18-82.

Osmer, S.R., L. Nash, G.L. Hover and T.J. Mazour (1982) "Utilization of AN/APS-94 Side-Looking Airborne Radar Systems In Search and Rescue" Report No. CG-D-14-82.

O'Neil, R.A., R.A. Neville and V. Thomson (1981) "Report of the Arctic Marine Oil Spill Program, Remote Sensing Project" Environment Canada.

Petro-Canada Exploration (1981) Internal Documentation.

Porter, N. and B.G. Young (1980) "Human Activities on the Ocean" SURSAT PROJECT - Experiment 23, Final Report, January.

REMOTEC (1980) "Field Evaluation of Sensors for Development of a Ship-Mounted Ice Hazard Detection System" Report to Petro-Canada Exploration Ltd.

Remondini, D.I.; M. Light, M.L. Everson, L. Nash, D.L. Good, and S.R. Osmer (1982) "A Pilot Study of Human Factors In SAR" Report No. CG-D-19-82.

REFERENCES - Cont'd.

Rollins, C.R. "A Cumulative Detection Probability Method" 28th Navy Symposium on Underwater Acoustics, Vol. 5, November 1970, pp. 121-133.

Simon, C. (1965) "Rapid Acquisition of Radar Targets from Moving and Static Displays" Human Factors, Vol. 7.

Siverton, Jr., W.E., R.W. Larson and J.S. Zelenka (1977) "Space Shuttle Search and Rescue Experiment Using Synthetic Aperture Radar" In. Proc. of the Eleventh International Symposium on Remote Sensing of Environment. Vol II, p. 1433-1442.

Theodorou, Dr. D.G. and J.C. Pickels (1971) "Salient Sensor Characteristics for LLLTV Systems" 5th Symposium on Photoelectric Image Devices, London, England.

U.S.C.G. Publication CG-308 (1973) Manual on Search and Rescue.

U.S. Naval Synoptic Observations, unpublished data.

U.S. Night Vision Laboratory, Fort Belvoir, unpublished data.

Weisinger J.R. (1984) "Analytical Techniques To Estimate Lateral Range Functions for Visual Detection". U.S.C.G. Contract No. DTCG26-83-C-0019.

Werstiuck, H.L., (1983) "COSPAS-SARSAT: A system Overview", International Electrical Electronics Conference, Vol. 1, Sept. 26-28.

Worsfold R.D., B.E. Fretts, J. Allen (1975) "The Use of Television for Remote Sensing" Remote Sensing of Environment. Vol. 4, No. 1.